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THE USES OF METEOROLOGICAL DATA IN LARGE SCALE AIR POLLUTION SURVEYS

Stanford Research Institute
Menlo Park, California

June 1958

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THE USES OF METEOROLOGICAL DATA IN LARGE SCALE AIR POLLUTION SURVEYS

Prepared by

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MENLO PARK, CALIFORNIA

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2151 BERKELEY WAY
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FOREWARD

This report, "The Use of Meteorological Data in Large Scale Air Pollution Surveys," was prepared to develop information on the air pollution climates of California and to demonstrate how existing meteorological data can be located, collected, and analysed for the study of air pollution. The study was made under contract for the State Department of Public Health by the Stanford Research Institute and was made possible by a demonstration grant to the State Department of Public Health from the U. S. Public Health Service. Direction of the investigation and preparation of the report were under the supervision of Mr. Gordon B. Bell of the Stanford Research Institute.

Summaries of California meteorological data will have general use in the study of air pollution in all the major climatological areas of the State. The report will also provide a guide to meteorological investigations in other areas where air pollution problems are being studied.

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Final Report

THE USES OF METEOROLOGICAL DATA IN LARGE-SCALE AIR POLLUTION SURVEYS

I Introduction

The California State Department of Public Health has become concerned with California's increasing air pollution problems. To assist local authorities with their individual problems, this agency has requested that Stanford Research Institute describe California meteorological data and the sources of such data, and to achieve the following objectives: to outline the uses of meteorological data in a large-scale study of air pollution climate; and to apply some of these data uses in the descriptions of air pollution climates as they pertain to the larger areas of California.

To accomplish these objectives, Stanford Research Institute submitted Proposal No. PS 57-52 in February 1957. This proposal subsequently, on June 1, 1957, was made a part of California State Contract No. 69 with Stanford Research Institute. This final report is in fulfillment of this contract.

This report first lists existing weather data sources, evaluates these sources, and indicates the cost of the reproduced data (Section III); describes various uses of meteorological data (Section IV); and discusses the general air pollution climatography of the State of California (Section V). Section V emphasizes in detail two general factors which must be considered by local authorities in conducting large-scale air pollution surveys: (1) air pollution distribution as dictated by meteorological conditions; and (2) air pollution distribution as affected by weather factors modified by natural topography.

These items in the body of the report are treated in some detail and for this reason represent fairly detailed reading for those not well versed in the meteorology field. However, the specific treatment of information should provide the reader with a generally comprehensive picture of the kinds of data which are necessary in any large-scale air pollution survey, methods of treating them, and obtainable results.

II Summary and Conclusions

Published climatological and meteorological summaries are sufficient for generally evaluating the air pollution potential in large areas. They are often insufficient for evaluating air pollution in areas as small as the size of a town or city.

The cost of published data summaries is reasonably modest and the quantity available is very large. Unfortunately, the information often lacks completeness with regard to geographical coverage and with regard to several types of data summarization. This means that a trained meteorologist often is required to interpret the available information. On the other hand, the meteorologist cannot always give a reliable assessment of the air pollution situation in local areas.

In general, the standard weather summaries can be interpreted to reveal: (1) the general pattern of air circulation on a monthly or seasonal basis; (2) the average natural ventilation of the area based on average daily wind movement data; (3) areas of naturally limited visibility (provided care is taken to eliminate data from stations influenced by man-made restrictions to visibility); (4) the general effect of topographical influences on weather variables; and (5) in areas where upper air data are available, the monthly and seasonal variations of the distribution of temperature with height.

A. Types of Available Data

The standard publications of the U.S. Weather Bureau provide a large reservoir of climatological and meteorological information. Large quantities of unpublished data also are readily available. The data customarily reported include observations of wind, temperature, precipitation, humidity, cloud cover, and sunshine, as well as aeronautically and agriculturally oriented observations such as visibility, cloud ceiling, snow cover, evaporation, solar radiation, and upper air conditions. This information is useful in defining gross weather conditions for any area of interest, but cannot always provide the refinements or coverage necessary for a detailed analysis of small areas.

The U.S. Weather Bureau publications that are most helpful to people concerned with air pollution are: Local Climatological Data (Supplement and Annual Summary); Climatography of the U.S., Series No. 30-4, Climatic Summary of the U.S., California Supplement No. 11-4; Climatological Data - California; Climatological Data - National Summary, and the Daily Bulletin of upper air data. Most of the California stations for which current and historical meteorological data are available are shown on the map of Figure 1.

The National Weather Records Center (Asheville, North Carolina) is a depository and data processing facility for all U.S. Weather Bureau and military weather stations. The Center can provide copies of original or processed data tabulations as well as special, custom, data reports.

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Available standard summaries of surface weather observations are catalogued in an Inventory of Unpublished Climatological Records. These summaries may be purchased from the Center for 5 to 35 cents per page, depending on the mode of reproduction. Special data tabulations specified by the purchaser cost $20 to $50 per station per year. Microfilmed upper air charts for soundings made at U.S. Weather Bureau stations and some military airports cost about $36 per station per year. For a cost of $60 per year, upper air data from four radiosonde and nine wind aloft stations in California can be obtained through a subscription to the Daily Bulletin (Upper Air Data) of Northern Hemisphere Data Tabulations.

Other important sources of meteorological information include the office of the State Climatologist, local Weather Bureau offices, agricultural experiment stations, district fire stations, departments of public works, private airports, public utilities, radio stations, and corporations. Cooperative sources of special data may include the Civil Air Patrol, soaring clubs, and high school science and 4-H clubs.

B. Uses of Data

Very broadly, meteorological data are used to assess the likelihood of natural and man-made pollution being accumulated in a restricted volume of air. If a period of accumulation produced by weather conditions lasts for too long, noticeable and possibly damaging air pollution will result. From this viewpoint, it is apparent that weather factors which restrict the natural flow of air or restrict the upward dissipation of the pollutants are important contributors to air pollution.

Surface wind conditions are a key factor governing pollution build-up in an area. Areas of low wind speeds, or where surface winds shuttle back and forth with little or no net movement, often are areas that have a high air pollution potential. Data based on hourly observations of wind movement, available from stations recording wind data continuously, can be interpreted to show these natural ventilation factors.

Data on surface winds can often be correlated with visibility to gain additional insight into the area's pollution potential. Smoke, haze, and fog that remain as a result of stagnant air are other indications of conditions favorable to pollution. Tabulations of consecutive hours of low wind speed reveal the important factor of persistence of poor natural ventilation.

The atmosphere's ability to disperse pollutants upward is a function of the air temperature variation with height. Upward dispersal is hindered wherever the atmosphere is "stable" -- that is, where warm air overlies colder air (a temperature "inversion"). The persistence of adverse stability conditions is as important a factor as the occurrence of wind stagnation in causing build-up of pollution. The significance of the local terrain in this connection must not be overlooked.

Total daily wind movement, atmospheric stability, the persistence of adverse climatic conditions, terrain features, and the amount and kind of pollution emitted to the air must all be taken into consideration in evaluating the air pollution potential of an area. Numerous attempts have been made in the past to derive generally meaningful measures of air pollution potential by relating one or more meteorological factors to the area's air pollution history. These attempts have not been totally successful because almost every area is sufficiently individual to be an exception to any general rule. In brief, trained meteorologists are required if the air pollution situation of any area is to be reliably gauged.

C. General Climatology of California

From the standpoint of climate, California is an extremely diverse state. It contains three more-or-less distinct zones: (1) the maritime zone, which lies along the coast and spreads inland to near-coast valleys wherever a major break occurs in the Coastal Range; (2) the intermediate zone, which consists largely of the Great Central Valley; (3) the continental zone, which is made up of the Northeast Plateau, and the Great Basin and desert regions to the southeast. Each of these zones has its characteristic patterns of climate that vary with the seasons. The mountainous areas of the state are characterized by a variety of local climates.

The maritime zone is probably the most pollution-prone portion of the state at present. The presence of persistent atmospheric stability plus low wind conditions during the fall months, particularly, combine with the sheltering influence of the terrain and the existence of large population centers to make the maritime zone an area of potential and actual pollution occurrence.

The intermediate zone (Central Valley) is the next most pollution-prone area. The stable atmospheric conditions which prevent upward dissipation of pollution are not quite as persistent as in the maritime zone. Low wind conditions persist mainly in areas sheltered by mountains. As population growth continues, it is possible that significant pollution build-up may occur irregularly.

The continental zones (Northeast Plateau and Desert-Basin regions) have climates during the winter season which may develop occasional conditions favoring local accumulation of pollutants. The likelihood of a major population increase as a contributing factor in these regions is small, however.

D. General Conclusions

This study has shown that standard climatological summaries can be used to demonstrate the general distribution of some weather conditions which are related to air pollution. In order to extend the usefulness of meteorological data in the study of air pollution, it is often necessary to refer to original records at considerable cost in time and money. Some recent revisions in published standard summary tabulations of climatological data have added to their usefulness in the study of air pollution. However, further progress in this direction is indicated, since it would facilitate the task of compiling meaningful meteorological information at reasonable cost. Consideration should be given, for example, to a summary tabulation permitting comparison of humidity and visibility occurrences. Experience has shown that low visibility associated with low humidity is a significant indicator of pollution accumulation. Another example is tabulation of prevailing wind directions by hour (including their relative frequency). Such data would assist in evaluation of space-time variations in the wind circulation. Publication of solar radiation data in the monthly state Climatological Data summary would add considerably to the usefulness of this document in compiling information related to air pollution. These data are now published only in the National Summary. These and other revisions which might result from consideration of the end-use of climatological data in the study of air pollution would enable air pollution control districts, public health officers, and others concerned with air pollution problems to fulfill their responsibilities more effectively.

In the study of air pollution it is often desirable to develop an equation which relates weather conditions to a pollution index. To date, such equations have been applicable only to a specific area or have included such a limited number of variables that the results are only a crude indication of pollution. Development of an equation having more or less general application might be possible if the following variables were included: wind movement as a function of the area of the region; atmospheric stability as a function of the effective depth of pollutable air; humidity, air temperature, visibility, and possibly solar radiation.

III Evaluation of Meteorological Data Sources

Familiarity with published and unpublished data sources will assist substantially in the study of air pollution climate. Economy of effort can be realized by knowing where to look for climatological data, and by exploiting sources of supplementary data.

In the discussion to follow, standard publications of climatological data are described. Their cost and availability are indicated. Various other data and information sources are also discussed. A survey of meteorological stations in California is provided to show the many sources for climatological data.

A. Standard U.S. Weather Bureau Publications

The U.S. Weather Bureau expends considerable effort to make available for public use a vast quantity of weather records. These are in the form of a number of standard publications which are issued regularly. Many of these publications are available on a subscription basis. Back issues of these publications usually are available at modest cost.

1. Climatological Data - California

This publication is issued monthly and as an annual summary for each state. The subscription cost including the annual summary is $2.50 per year. Individual copies cost 20 cents. Subscriptions and individual copy requests are handled by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Requests for serial groups of back issues should be directed to the National Weather Records Center, Asheville, North Carolina or the Office of the Chief, U.S. Weather Bureau, Washington, D.C.

This publication contains temperature and precipitation data on daily, monthly, and seasonal bases; monthly and seasonal heating degree days; evaporation and wind; and supplemental summarized data from selected Weather Bureau airport stations. Maps showing the statewide distribution of total monthly precipitation and average temperature (included since July 1956) and the location of some 900 climatological stations are included. In addition to the data tabulations, a station index is provided. The data are fully annotated and are interpretable without referring to other information. The annual summary contains information which is a composite of the 12 monthly issues.

2. Local Climatological Data

This publication consists of three summary tabulations based on one month's hourly observations for a single station. The summary titled Local Climatological Data contains daily data tabulations of temperature, precipitation, wind, sunshine, sky cover, and special phenomena. Hourly precipitation data by days are included for most stations. The summary titled Local Climatological Data, Supplement, currently contains tabulations of combined data such as temperature and wind speed-humidity occurrences, wind direction and speed, hourly and daily precipitation, ceiling and visibility, weather occurrences by hour of day, weather occurrences by wind direction, and average weather for synoptic hours. Included also is a complete tabulation of hourly observations of sky cover, visibility, ceiling, station pressure, psychrometric, and wind data. Prior to July 1956 the supplement included a tabulation of hourly temperatures in place of weather occurrences by wind direction and did not contain the tabulation of hourly observations. The annual summary is called Local Climatological Data with Comparative Data. It contains a narrative climatological summary, a summary tabulation of meteorological data, a summary of normal, mean, and extreme occurrences of temperature, data on precipitation, wind, cloud cover, sunshine, and special phenomena; average monthly temperatures and total monthly precipitation since 1900; monthly and seasonal degree days; monthly and seasonal snow fall; and a history of station location.

Prior to September 1952, the Local Climatological Data (LCD) and LCD, Supplement were known as Station Meteorological Summary (WB Form 1001c) and Special Meteorological Summary, respectively, and were published for a few selected stations. Before September 1949, a mimeographed Station Meteorological Summary (WB Form 1030) was published by selected stations.

The subscription price for the LCD and LCD, Supplement (and an annual summary if published) is $1.50 per year. Single copies cost 15 cents. Available back issues may be procured from the National Weather Records Center, Asheville, North Carolina.

California stations for which the LCD are available currently include Bakersfield, Bishop, Blue Canyon, Burbank, Eureka, Fresno, Los Angeles, Mt. Shasta, Oakland, Red Bluff, Sacramento, Sandberg, San Diego, San Francisco, and Santa Maria.

3. Climatography of the United States No. 30-4

This publication is issued for some first order stations in California (as well as for other states) and is a 5-year summary of hourly observations. The tables are similar to those in the monthly publication called Local Climatological Data, Supplement, except that percentage frequencies are given in Table B (Wind Direction and Speed), D (Ceiling-Visibility), and E (Sky Cover, Wind and Relative Humidity). A brief description is usually given of station location, surrounding topography, and smoke sources. A shaded, topographical map is included. The period of record included is shown above each tabulation.

The publication is available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. at 10 cents per copy. The airport stations in California for which this 5-year summary of hourly observations has been published include Burbank, Fresno, Los Angeles, Oakland, Sacramento, San Diego, and San Francisco.

4. Climatic Summary of the U.S. California Supplement No. 11-4

Scheduled for issuance during 1958, this publication is part of the Climatography of the United States series and will contain tabulations by station, of data similar to those contained in the monthly Climatological Data. The data will cover 1931 to 1952. Also listed are: monthly averages, annual averages, extremes of temperature and precipitation, and an index of stations and station history. This document is an extension of Bulletin W, Climatic Summary of the United States (Sections 15, 16, 17, and 18), which covers the period from the beginning of record to 1930 for each California station.

The cost of the California Supplement No. 11-4 is expected to be about 35 cents. Sections of Bulletin W are available in reference libraries and at the State Climatologist's Office in San Francisco. Publication announcement of California Supplement No. 11-4 will appear in the Monthly Catalogue of the U.S. Government Printing Office.

5. Terminal Forecasting Reference Manual

This document is not intended for general public consumption. It is available, however, for first order Weather Bureau stations as listed above in subsection 3, plus Arcata, Bakersfield (Kern County Airport), Red Bluff, and Santa Maria.

As a means of becoming familiar with characteristic weather conditions at each of these stations, the document contains information on local topography, smoke sources, special weather occurrences, and mean wind and visibility conditions.

This Summary is available from the Superintendent of Documents. The cost is 10 cents per station copy.

6. Key to Meteorological Records Documents No. 1.1

This publication is issued by the state and has the title of Substation History. It contains, for all except first and second order stations, copies of WB Form 530-1, which lists the history of station location, previous names of the station, description of instrument exposure, instruments used, location of original records, where records were published, and dates of first and last observations.

The California Substation History is available at $1.50 per copy from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

The information contained in the History could be helpful in making a canvas of climatological stations during initial phases of an air pollution survey. However, documents described in subsection 4 above, would provide more climate information.

7. Climatological Data - National Summary

This monthly publication is a source of solar radiation data. It also contains constant level summaries of upper air data from Oakland, Santa Monica*, San Diego, and Santa Maria radiosonde stations. Except for upper air data, both tabular and map presentations of weather data are given. The map presentations provide an inclusive picture of spatial distributions and standard climatic elements.

The subscription price from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., for monthly and annual issues is $4.00 per year. Individual copies are 30 cents. Serial groups of back issues may be procured from the National Weather Records Center, Asheville, North Carolina, at moderate cost.

8. Northern Hemisphere Data Tabulations

Upper air data are available from the Daily Series, Synoptic Weather Maps, Part II, Northern Hemisphere Data Tabulations, Daily Bulletin. In this publication, daily rawin** and radiosonde data (including significant levels) for Oakland, Santa Maria, Santa Monica, and San Diego are tabulated. Also included are daily winds aloft data for Bishop, Burbank, Fresno, Oakland, Red Bluff, Sacramento, Sandberg, Santa Maria, and Santa Monica. This publication, first published in 1956, is available for $5 per month from the U.S. Government Printing Office, Washington, D.C. Individual daily bulletins are priced at 25 cents per copy. Back issues are available at these same prices from the National Weather Records Center in Asheville, North Carolina.

B. National Weather Records Center

The National Weather Records Center (NWRC) located in Asheville, North Carolina, is administered by the U.S. Weather Bureau, Office of Climatology. The Center is a depository and data processing facility for all weather records generated by the U.S. Weather Bureau, the Air Force Air Weather Service, and the Navy Aerological Service. The data on file are in the form of original records or are on IBM cards.

The Center can supply, on a prepaid, at-cost basis, copies of original or processed data tabulations,***or special tabulations programmed from the extensive IBM files.

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* Since April 1956 and June 1956, respectively.

** Winds determined with directional radio equipment.

*** Copies are available as photostats costing 35 cents per page, Ozalid reproductions at 10 cents per page, or microfilm at 5 cents per frame. Usually no choice between photostat and Ozalid reproduction is possible since the type of reproduction depends on the form of the original records. Microfilm copies are the only alternative to the rather expensive photostat copies.

The NWRC is the principal source for records necessary to examine the space-time variations of weather over a large area. Access to these weather records can be facilitated by providing specific instructions concerning the type and form of data desired.

Two documents are available which will assist in ordering already summarized weather data. One is entitled Inventory of Unpublished Climatological Tabulations and the other is the WRPC (IBM) Card File History.

1. Inventory of Unpublished Climatological Tabulations

This publication is available from the Superintendent of Documents for 90 cents. It is issued as a preface and table of contents plus 10 sections. Listed and illustrated are a variety of data tabulations available from the National Weather Records Center, Asheville, North Carolina.

In Sections 1 and 1a, U.S. Navy summaries of Monthly Aerological Records are described. Twenty-two California stations are listed for data prior to 1945 and 13 are listed for data from 1945 to 1952. Air Force Summaries of Surface Weather Observations are listed in Section 2. Forty-seven stations are listed for California. Some of the stations operated only during World War II, however. Section 3 lists Weather Bureau Wind Summaries by Combined Velocity Groups (Form 1139D) for 50 California stations. Sections 4 through 7 list various special tabulations of wind, visibility, cloud ceilings, psychrometric data, and general weather conditions. Sections 8 through 10 list summaries of upper air data for Weather Bureau and military stations.

These tabulations are the principal source of historical weather data for military facilities. They are valuable corroborative data and often provide hourly observations at locations for which there are no similar Weather Bureau observations.

Most of these records are available on microfilm or may be had as full-record-size reproductions. The cost ranges from about $4 to $20 per station per year.

2. WRPC (IBM) Card File History

This unpublished record of climatological and meteorological data on IBM punched cards is available for California as a 114-page photocopy from the National Weather Records Center (NWRC) for $39.90. All classes of observation stations are listed by number, location, and elevation. The IBM card data available for each station are indicated according to climatological and meteorological class. Climatological data are temperature, daily precipitation, weather occurrences, river level, evporation (including monthly wind movement recorded by an anemometer 2 ft above ground level), and hourly precipitation.

Meteorological data are WBAN No. 1 - Hourly Surface Weather Observations,* WBAN No. 2 (discontinued) - Six-hourly Surface Weather Observations, WBAN No. 3 - Daily Weather Summary, and WBAN No. 4 and WBAN No. 5 - Upper Air Data. Stations having special instrumentation such as triple register, pyrheliometer, thermographs, barographs, or radar are indicated.

The information is of value if extensive machine manipulation of punched card data is contemplated. Special cross tabulations can be executed with proper programming of punched card records. The cost will vary from $20 to $50 per station per year of data depending on the complexity of the special tabulation. Since the unit cost is rather high, punched card data manipulations are not always economically adapted to the broad scope of weather data evaluation usually involved in large-scale surveys. For special local evaluations such as the long-term trend of visibility relative to the occurrence of low humidity, a special tabulation based on hourly data from a single representative station could be economically feasible. This is a type of tabulation which could not be prepared from published summaries of hourly observations.

3. Upper Air Data

Data on the distribution of temperature with altitude for the determination of inversion conditions are available from NWRC as Form Nos. WBAN-30 (tabular form) or WBAN-31A (adiabatic chart). These forms provide a means for obtaining data from the regular observations stations as well as from the military airports where nonserial data are acquired. The Weather Bureau stations currently making upper air observations are Oakland, Santa Maria, Santa Monica, and San Diego. Historical records are available for the above stations as well as for Long Beach, Auburn, Merced (Castle AFB), and Inyokern (Naval Ordnance Test Center). These records are available on microfilm at a cost of approximately $3 per month for 62 frames representing two soundings per day by each station. Prior to July 1957 most soundings were scheduled at 0700 and 1900 PST. Since July 1957 the soundings have been taken at 0400 and 1600 PST.

C. State Climatologist's Office

The Weather Bureau State Climatologist's Office for California is located in Room 557, Federal Office Building, 50 Fulton Street, San Francisco 2.

Due to a limited staff, the State Climatologist is able to provide only general climatological services. However, files of published and unpublished climatological data for California stations are available for transcription by any person seeking historical weather information. A file of climatological publications issued by the Weather Bureau for California is maintained.

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* Photostat copies of Form WBAN 10A which contains all hourly data punched on IBM card WBAN 1 are available from NWRC for 35 cents per page. One month of data costs from $10.50 to $21 depending on the number of pages. Microfilm copies of WBAN 10A are also available at 5 cents per frame.

As a historical data source, the State Climatologist's Office provides quick and free accessibility.

D. Local Weather Bureau Offices

The weather data files of all Weather Bureau offices are available in their respective offices for public perusal and for transcription of data by the user. The amount of time that data are kept in the files varies from office to office -- usually all teletype data are disposed of after 30 days. Only processed data which are used directly in the generation of forecasts may be kept for a longer period.

It is possible that special studies by staff meteorologists may involve processed data in a form valuable to air pollution studies. The possible existence of such data should be inquired about.

No Weather Bureau office is permitted to dispense special services unless authorized by higher authority. However, the staffs of every office will render assistance in the procurement of data.

E. Local Government and Private Sources

Special interest in local weather factors and often the lack of a nearby U.S. Weather Bureau observation station have resulted in many unofficial observing stations. Weather data must be procured directly from the agency or individual operating the station. Historical weather data may or may not be available.

Wind data from unofficial stations often can be a valuable supplement to the matrix of wind data from Weather Bureau stations in a large-scale air pollution investigation. If a sufficient number of unofficial records can be brought to bear, greater resolution of fine-scale weather aspects may be possible in a given area of interest.

Many local government agencies as well as private operations are likely sources of weather data. State, municipal, and county agencies whose activities are affected by the weather are likely weather data sources. These include agricultural experiment stations, State Division of Forestry, district fire stations, departments of public works, and city engineer's offices. The quantity and kind of data available will vary widely with the agency function. If records of wind conditions are kept they are most likely based on "spot" observations. The data continuity may be somewhat less than desirable. Even small segments of serial hourly data can be helpful.

Private airports often maintain or can be prevailed upon to obtain hourly logs of wind conditions. Wind data based on an airport's wind sock observations are valuable only for direction information.

Public utilities and corporations whose operations depend on the weather often take a variety of weather observations and may possess fairly long-term records of data.

F. Special Sources

The cooperation of various groups having special interest in the weather can be enlisted to assist in the collection of weather data during the course of an air pollution survey.

The Civil Air Patrol, for example, can assist periodically in acquiring data on the vertical temperature profile and its spatial variation. If the aircraft used do not have temperature sensing equipment, they can be provided temporarily with a simple piece of equipment similar to the Model 170-100-1 temperature indicator unit manufactured by Beckman-Whitley Inc., San Carlos, California. The unit should be obtained with a sensor element designed for mounting on the exterior of an aircraft.

Similar cooperation may be solicited from any soaring or sail plane clubs which may operate occasionally in the area of interest.

High school science and 4-H clubs could assist by taking visibility observations or wind observations after being suitably instructed.

There are a number of stations throughout the state which take evaporation data from standard-size pans. Run-of-the-wind anemometers mounted 2 or 3 ft above ground level are used in conjunction with many of the evaporation pans. These data, which would be in the form of miles of wind per 24 hours, could be corrected to the standard anemometer level (20 ft) and used in the analysis of wind movement in the area of interest. These data are published regularly.

G. Survey of California Meteorological Stations

There are more than a thousand weather observing stations in California. Observations at a large majority of the stations include only one or two weather variables (usually temperature and precipitation). These stations are classed as climatological stations.

Active stations which record hourly or (in some cases) three-hourly observations of all principal weather variables number about 60. They include civilian as well as military facilities. Except for U.S. Weather Bureau City Offices and U.S. Coast Guard Stations, all other observing points are located in conjunction with aeronautical facilities. These include U.S. Weather Bureau airport stations, U.S. Civil Aeronautics Administration Stations, military test center, and Naval Air Station and Air Force Base facilities.

Historical data used in the climatography section of this report are based on the records from about 75 stations. Some of these stations operating during the latter years of World War II and are currently inactive. The locations of these stations are shown on the map of Figure 1. The map is shaded to show schematically the intermediate and mountainous areas that separate the principal valleys, basins, and plateau areas of California.

With the exception of the Northeastern Plateau Area (see Figure 1) the distribution of stations reporting complete, standard meteorological data affords reasonable coverage of the various areas. Supplementary wind data which must be corrected to be comparable to regular wind observations are available from records of accumulating anemometers located at evaporation stations. These stations are also located on the map of Figure 1.

For the gross evaluation of large areas such as are included in the air pollution climatography section of this report (Section V), the distribution of meteorological stations shown in Figure 1 appears to be adequate. Localized consideration of areas smaller than one of the principal valleys or basins would require supplementary data in order to reveal the fine-scale aspects of air pollution conditions. These requirements are discussed in Section IV and to some extent in Section V, E-4 and E-5.

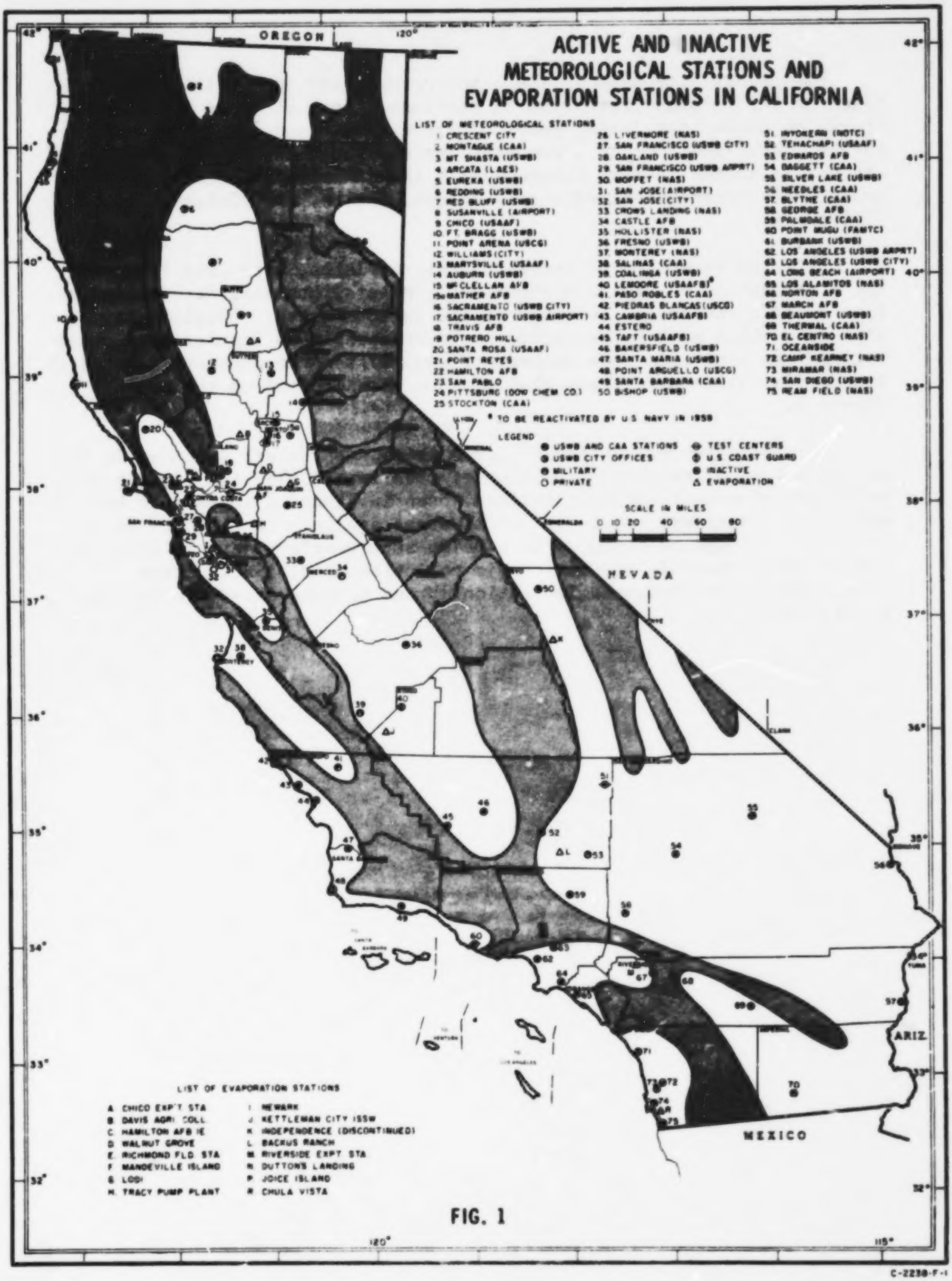
ACTIVE AND INACTIVE METEOROLOGICAL STATIONS AND EVAPORATION STATIONS IN CALIFORNIA
LIST OF METEOROLOGICAL STATIONS
1 CRESCENT CITY
2 MONTAGUE (CAA)
3 MT SHASTA (USWB)
4 ARCATA (LAES)
5 EUREKA (USWB)
6 REDDING (USWB)
7 RED BLUFF (USWB)
8 SUSANVILLE (AIRPORT)
9 CHICO (USAAF)
10 FT. BRAGG (USWB)
11 POINT ARENA (USCG)
12 WILLIAMS (CITY)
13 MARYSVILLE (USAAF)
14 AUBURN (USWB)
15 McCLELLAN AFB
15a MATHER AFB
16 SACRAMENTO (USWB CITY)
17 SACRAMENTO (USWB AIRPORT)
18 TRAVIS AFB
19 POTRERO HILL
20 SANTA ROSA (USAAF)
21 POINT REYES
22 HAMILTON AFB
23 SAN PABLO
24 PITTSBURG (DOW CHEM CO.)
25 STOCKTON (CAA)
26 LIVERMORE (NAS)
27 SAN FRANCISCO (USWB CITY)
28 OAKLAND (USWB)
29 SAN FRANCISCO (USWB ARPRT)
30 MOFFET (NAS)
31 SAN JOSE (AIRPORT)
32 SAN JOSE (CITY)
33 CROWS LANDING (NAS)
34 CASTLE AFB
35 HOLLISTER (NAS)
36 FRESNO (USWB)
37 MONTEREY (NAS)
38 SALINAS (CAA)
39 COALINGA (USWB)
40 LEMOORE (USAAFB)*
41 PASO ROBLES (CAA)
42 PIEDRAS BLANCAS (USCG)
43 CAMBRIA (USAAFB)
44 ESTERO
45 TAFT (USAAFB)
46 BAKERSFIELD (USWB)
47 SANTA MARIA (USWB)
48 POINT ARGUELLO (USCG)
49 SANTA BARBARA (CAA)
50 BISHOP (USWB)
51 INYOKERN (NOTC)
52 TEHACHAPI (USAAF)
53 EDWARDS AFB
54 DAGGETT (CAA)
55 SILVER LAKE (USWB)
56 NEEDLES (CAA)
57 BLYTHE (CAA)
58 GEORGE AFB
59 PALMDALE (CAA)
60 POINT MUGU (FAMTC)
61 BURBANK (USWB)
62 LOS ANGELES (USWB ARPRT)
63 LOS ANGELES (USWB CITY)
64 LONG BEACH (AIRPORT)
65 LOS ALAMITOS (NAS)
66 NORTON AFB
67 MARCH AFB
68 BEAUMONT (USWB)
69 THERMAL (CAA)
70 EL CENTRO (NAS)
71 OCEANSIDE
72 CAMP KEARNEY (NAS)
73 MIRAMAR (NAS)
74 SAN DIEGO (USWB)
75 REAM FIELD (NAS)
* TO BE REACTIVATED BY U.S. NAVY IN 1959
LEGEND
USWB AND CAA STATIONS
USWB CITY OFFICES
MILITARY
PRIVATE
TEST CENTERS
U.S. COAST GUARD
INACTIVE
EVAPORATION
SCALE IN MILES
0 10 20 40 60 80
LIST OF EVAPORATION STATIONS
A CHICO EXP'T STA
B DAVIS AGRI COLL
C HAMILTON AFB IE
D WALNUT GROVE
E RICHMOND FLD STA
F MANDEVILLE ISLAND
G LODI
H TRACY PUMP PLANT
I NEWARK
J KETTLEMAN CITY ISSW
K INDEPENDENCE (DISCONTINUED)
L BACKUS RANCH
M RIVERSIDE EXPT STA
N DUTTON'S LANDING
P JOICE ISLAND
R CHULA VISTA
OREGON
NEVADA
ARIZ.
MEXICO
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°

FIG. 1

C-2238-F-1

IV Uses of Meteorological Data

A. Introduction

A large-scale air pollution survey usually requires the definition of gross weather conditions as affected by the area's geographic location. Existing climatic summaries that are available from the State Climatologist may be used. If such are not available, the principal climatic features can be derived from the climatological data records. Economy of effort can be realized by considering averages of climatic elements on a seasonal basis.

When the area of interest is sufficiently large (e.g., the San Joaquin Valley) it may be possible with the aid of climatological data to obtain a first approximation of weather conditions potentially responsible for the gross accumulation of air pollution. The seasonal variations of such climatic elements as the predominant wind circulation (based on wind direction records) and the geographic distribution of mean wind movement (based on mean wind speed records) can be used to indicate the gross character of the natural ventilation in the area. Sub-areas in which pollution is likely to occur because of limited natural ventilation may be revealed. Finer-scale delineation of the air circulation in suspect areas may be necessary. Sufficient data should be obtained, based on hourly observations, to define the space-time variation of the wind circulation and its affect on the natural dispersal of pollutants. The effect of topographic features on the circulation must also be considered.

In the following sub-sections various methods are described for the manipulation of meteorological data. The methods are designed to demonstrate the graphical and tabular uses of data which emphasize the seasonal variations of natural ventilation factors and the persistence of weather conditions causing the accumulation of air pollution. Methods for the spatial interpolation and extrapolation of data are included also.

B. Meteorological Data Applications

1. Surface Wind Data

Standard tabulations of surface wind data based on hourly or three-hourly observations can assist in the delineation of areas having similar air pollution climates. The correlation of wind data with simultaneous occurrences of other weather elements also may provide a clearer understanding of the significance of conclusions based on wind data alone.

Monthly wind data tabulations in the published and unpublished weather summaries referred to in Section III, A-2 and 3, and B above, have been fairly well standardized by the various weather services. The absolute or percentage frequencies of wind directions (usually to 16 points of the compass) are tabulated in most summaries by arbitrary speed groups.

The average speed for each direction is shown also in Weather Bureau and Air Force summaries, while the Navy Aerological summaries and some of the earlier unpublished Weather Bureau summaries (WB Form 1139D) do not. The total occurrences in each wind speed group are included in all summaries. Each of the weather services uses somewhat different class intervals for the speed groups. This is due partially to the fact that the Navy tabulates surface wind speed in knots while the other two weather services use miles per hour. Conversion of Navy wind speed data to miles per hour (multiply by 1.15) is necessary to make the data comparable.

An example of the tabulation format used in Weather Bureau publications for wind data based on hourly observations is illustrated in Table I.

Table I

WIND DIRECTION AND SPEED OCCURRENCES

Direction	Hourly Observations of Wind Speed (in miles per hour)										
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 over	Total	Av. Speed
N etc. to 16 Points											
NNW											
Calm											
Total											

Tabulations as in Table I and of wind speed groups by hour are included in the Weather Bureau Local Climatological Data Supplement (LCD). Since July 1956 tabulations of all hourly observations have been included in the LCD and hourly wind direction and speed summaries can be extracted from these data. Navy Aerological Summaries, of the revised SMAR form, contain tabulations by hour of wind direction occurrences and of wind speed groups. Hourly wind summaries are not included in Air Force weather summaries. To obtain these would require photostatic or microfilm copies of the original Air Weather Service records from the National Weather Records Center in Asheville, North Carolina. Much of these data are on punched cards and hourly summaries can be ordered at somewhat less expense ($15 to $20 per station year).

If a sufficient number of stations are located in the area of interest for which monthly and hourly wind data summaries can be obtained, the data can be used in several ways to illustrate the natural wind ventilation. The spatial variation of the predominant wind circulation or the average daily variation of the wind can be illustrated by plotting the appropriate data on a map of the area. The data are then subjected to streamline analysis. The number of stations required to provide adequate coverage depends on the complexity of the terrain and the scale of circulation features desired. Reasonably adequate analyses of the gross circulation patterns can be made with data from 3 to 6 stations per 800 to 1000 square miles. The most frequent wind direction and average speed for each station are plotted as vectors or wind arrows which fly with the wind. The wind speed is plotted as a numerical value. The interrelationship of the individual data can be demonstrated with the use of streamlines. If the individual making the analysis has had sufficient experience in drawing streamlines, the freehand drawing of these can produce realistic results. If this is not the case, the Sandstrom method of streamline analysis should be applied (1)*. The method consists of four steps: (1) the numerical value of the wind direction in tens of degrees is plotted at each station (e.g. 270 degrees representing a west wind would be plotted as 27); (2) draw isogonic lines through stations having the same wind direction or interpolate such lines between stations; (3) draw short-line segments across the isogons representing the distribution of wind directions; and (4) connect these short-line segments with tangent curves. These curves will represent the streamlines. (See maps of Figures 10 through 13 in Section V.)

The percentage frequency of each predominant wind direction can be plotted near the station circle as a means of evaluating the spatial variation of wind steadiness. The highest frequencies will be arranged in areas where terrain features favor wind channelization or maximum exposure to the circulation of surface winds. The lowest frequencies will be arranged in areas of sheltering by terrain features and in areas of opposing wind flows.

The spatial distribution of wind speed in excess of a certain value (e.g. 3 mph) can be displayed by plotting for each station the percent of the time during a month when hourly observations of wind speed are in excess of the selected value. The matrix of data can be analyzed by drawing lines of constant percentage frequency. Areas of highest frequency will correspond to areas of strongest winds and vice versa. In this way areas of consistently low average wind speed can be made to stand out in a readily discernable manner. Examples of this method of illustration are executed for the State of California in Figures 14 through 17 of Section V, for the four mid-season months of January, April, July, and October.

Another method of illustrating the distribution of wind movement can be derived by calculating mean miles of wind per 24 hours. These data can be computed from the mean monthly wind speed for stations recording hourly observations (primary data) as well as from the total miles of wind tabulated for evaporation stations in Table 6 of the Weather

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* Refers to list of references at end of report.

Bureau publication called Climatological Data, California (see Section III, A-1). The wind data at evaporation stations are based on daily readings taken from totalizing anemometers which indicate the total miles of wind regardless of direction. These anemometers are mounted only a few feet above the ground plane and the data from them are not comparable to those from anemometers upon which hourly observations of wind are based. The totalizing anemometer data can be corrected to the height of 20 ft using the equation $V_2 = V_1 Z^a$ where V_1 is average wind speed at evaporation pan level derived from the monthly total miles of wind, and V_2 is the speed at height Z, "a" represents a constant. It has been found in practice that the value of Z^a varies between 1.7 and 3.0 for wind speeds in miles per hour depending on the exposure of the station. Since these data are supplementary to any matrix of data based on hourly observation plotted on a map, the choice of a wind correction factor for a particular evaporation station can be made to bring the result into reasonable relationship with the primary data. Analysis of the map plotted data with isolines having a gradient of 20 or 50 miles of wind will reveal characteristic areas of wind stagnation. These results will be on a monthly basis and will demonstrate the seasonal variations in 24-hourly wind movement. Since 120 miles of wind per 24 hours is equivalent to an average hourly wind speed of 5 mph, the areas circumscribed by the 120-mile isoline will represent areas which are poorly ventilated on the average by the natural wind. An example of this form of wind data presentation is shown in Figure 18 of Section V.

In areas where the daily wind pattern undergoes reversals of direction or where the only daily change is variation of wind speed, the resolving of hourly wind data into arbitrary time segments is a convenient basis for defining not only daily variations but also wind persistence. Both of these aspects are important delineators of natural ventilation. In the former case, the best means of presenting characteristic variations in hourly wind data is by graphical display of streamlines on a topographic map of the area of interest. The same method of streamline analysis previously described can be applied to the matrix of wind data plotted for each time interval.*

To prepare the hourly wind data arrange a tabulation for each station recording such data as shown schematically in Table II.

---

* To apply streamline analysis successfully to a specified area, data should be available from 3 to 6 stations per 1000 square mile of area.

Table II

4-HOURLY OCCURRENCES OF WIND DIRECTION

Time (hours of day)	00-03[a]	04-07	08-11	12-15	16-19	20-23
Wind Direction						
N						
NNE						
etc. to 16 points						
NNW						
Calm						

---

[a] Refers to wind observations for first four hours of day.

Using the tally method, tabulate the hourly direction data for appropriate 4-hourly time intervals according to the 16 directions as well as calm (no wind). Use all days of a given month for as many months of data as are available -- such as November for 1945 through 1949. The most frequently occurring wind direction during each 4-hourly period of the day is then selected as the wind direction to plot as a vector or wind arrow on the map for the particular station. (The second most frequent direction may be plotted as a dotted vector if desired.) The mean wind speed for the same 4-hourly period is computed simply as the arithmetic mean of all wind speeds occurring during the period and is plotted as a numerical value at the station location. Six groups of data will result for each station. After the streamline analysis, the six 4-hourly mean maps can be arranged in a single grouping demonstrating the daily wind variation typical of the month chosen. An example of this form of data presentation is given in Figure 2 which shows the 4-hourly variation in surface wind circulation for November 1949. The 00-04 hrs and 04-08 hrs maps display the character of the night time drainage wind flow from the mountainous structures in the upper part of the maps. The transitional stage of wind direction reversal is displayed in the map for 08-12 hrs. The afternoon flow pattern of the valley breeze is displayed in the map for 12-16 hrs, while the map for 16-20 hrs shows the late afternoon and early evening transitional flows. Finally, the 20-24 hrs map displays the re-establishment of the drainage flow from the mountains. An analysis of this sort also will reveal localities subject to repeated wind stagnation. Through comparison of months any seasonal variation in the tendency for pollution to be moved back and forth within the area will be indicated.

Another convenient and quickly interpretable form of presenting the average daily variation of wind direction and speed for a single station is shown in Figure 3. This method of data presentation has been used by the Bureau of Air Sanitation, State Department of Health. The

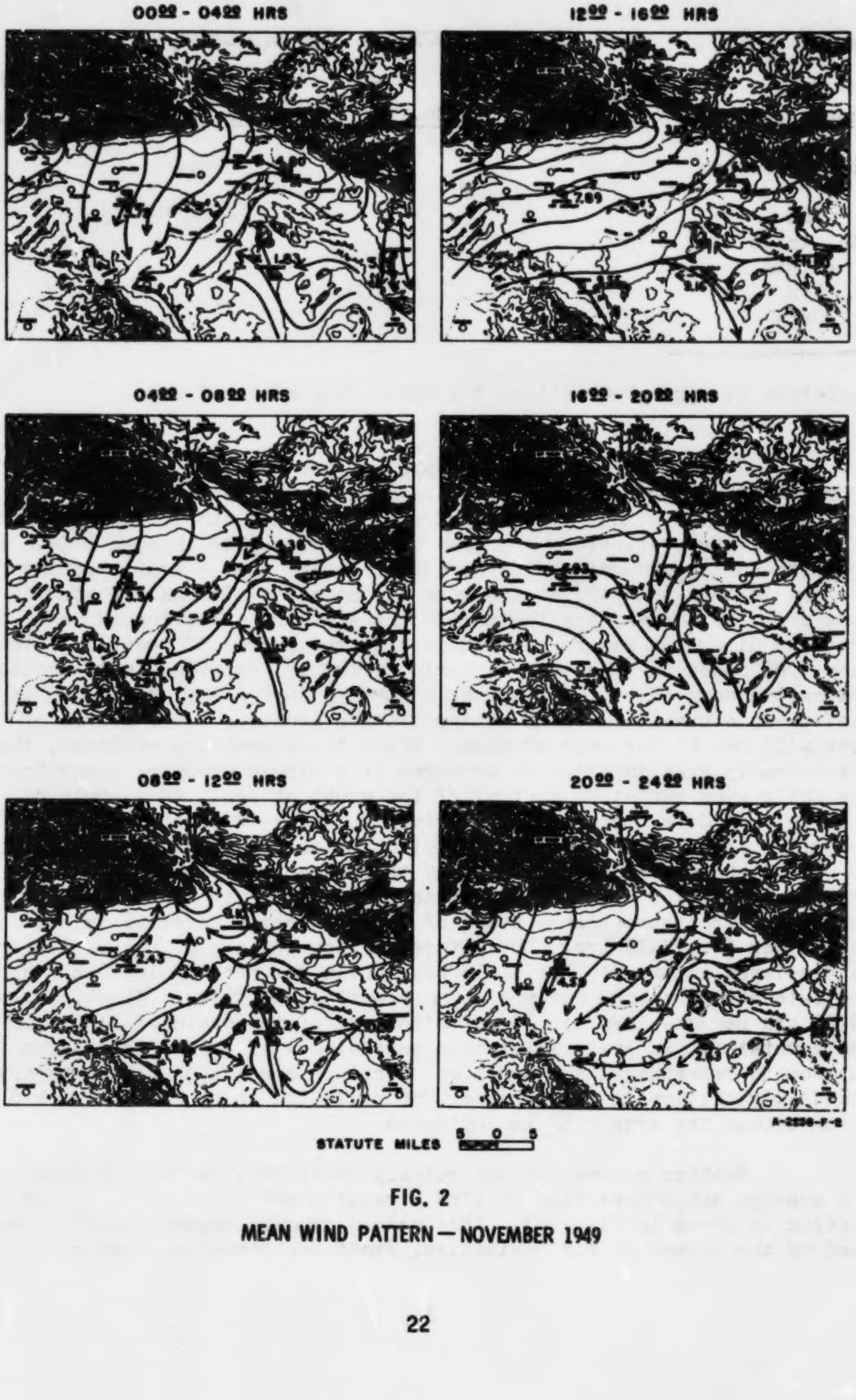
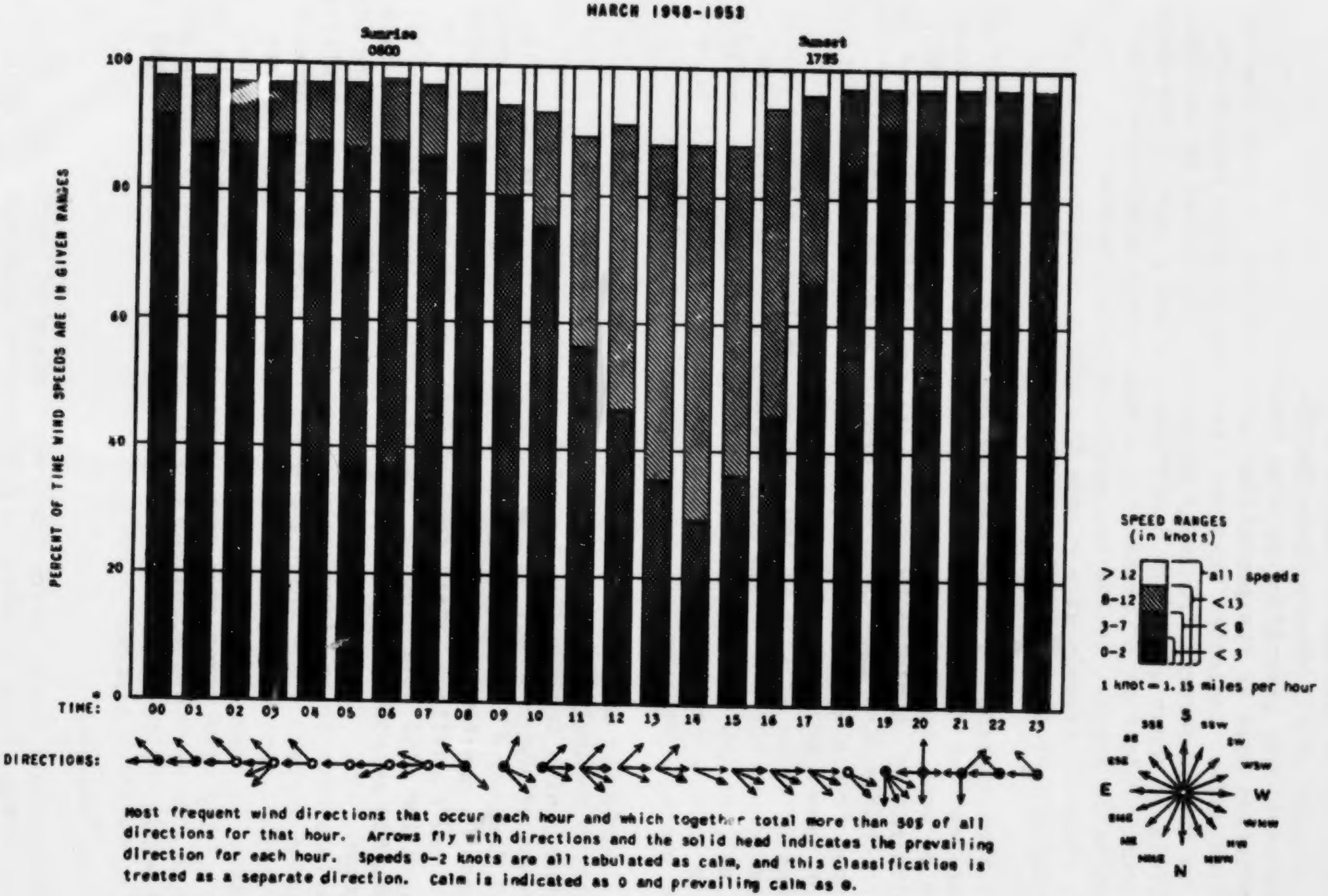

00^{00} - 04^{00} HRS
12^{00} - 16^{00} HRS
04^{00} - 08^{00} HRS
16^{00} - 20^{00} HRS
08^{00} - 12^{00} HRS
20^{00} - 24^{00} HRS
A-2230-F-2
STATUTE MILES 5 0 5

FIG. 2

MEAN WIND PATTERN — NOVEMBER 1949



Most frequent wind directions that occur each hour and which together total more than 50% of all directions for that hour. Arrows fly with directions and the solid head indicates the prevailing direction for each hour. Speeds 0-2 knots are all tabulated as calm, and this classification is treated as a separate direction. Calm is indicated as o and prevailing calm as ●.

* Observations made during hour shown.

A-8830-F-3

FIG. 3

HOURLY WIND SUMMARY— N.A.S. MIRAMAR

histogram portion of Figure 3 shows the percentage of the time wind speed occurrences are in an arbitrary speed range for each hour of the day. The wind directions plotted for each hour show those whose frequencies total 50 percent of all observations for the hour. The solid headed arrows represent the prevailing or more frequent direction. The filled center indicates calm as the prevailing condition for the hour whereas the unfilled center indicates that the frequency of calms merely contributes to the 50 percent frequency criterion. No filled or unfilled center circle is shown when calm conditions are not a part of the data for the hour. This form of presenting a mean hourly wind summary can furnish valuable support to the map method of data presentation shown in Figure 2, since it reveals at a glance the hourly changes in low wind speed conditions at a given station.

Each station for which data on punched IBM cards are available can be analyzed for the occurrences of consecutive hours of wind speed less than or equal to a certain value such as calm, 3 mph, and 7 mph. The results can be tabulated by the machine manipulation of punched cards containing hourly wind data as in the example shown in Table III.* This is condensed from a larger machine tabulation. The tabulation displays through an ascending scale of consecutive hours the total number of occurrences of three classes of low wind speeds during a 5-year period for each month of the year. The most frequent class of consecutive hours as well as the greatest number of consecutive hours are easily comparable on a monthly basis. An analysis such as this is of value in assessing probable duration of adverse natural ventilation.

A simpler and less costly method of evaluating the monthly variations in natural ventilation can be based on most wind frequency tabulations, which include the frequency of occurrence by arbitrary wind speed groups of the standard wind directions (see Table I). By using the total frequency of all directions for each wind speed group a graphic display can be constructed which allows the ready comparison by months of wind speed conditions. This form of data presentation is shown in Figure 4, using wind data based on hourly observations at Fresno, Calif. during the mid-season months of January, April, July, and October from 1950 through 1955. The cumulative frequency or percent of time the wind speed is less than an arbitrary value is plotted relative to a probability scale versus a speed scale which increases from right to left for each monthly period. Another ordinant scale is provided showing the mean daily number of hours the wind speed is less than a specified value. The size of the area under each curve connecting the plotted points is a function of the over-all windiness and in the comparison of months allows the less windy months, as represented by the smallest enclosed areas, to be singled out at a glance.

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* For the example shown, which involves 5 years of hourly wind data, machine manipulation of about 43,000 punched cards was necessary. About 3.6 hrs of machine time were required at an approximate cost of $180.

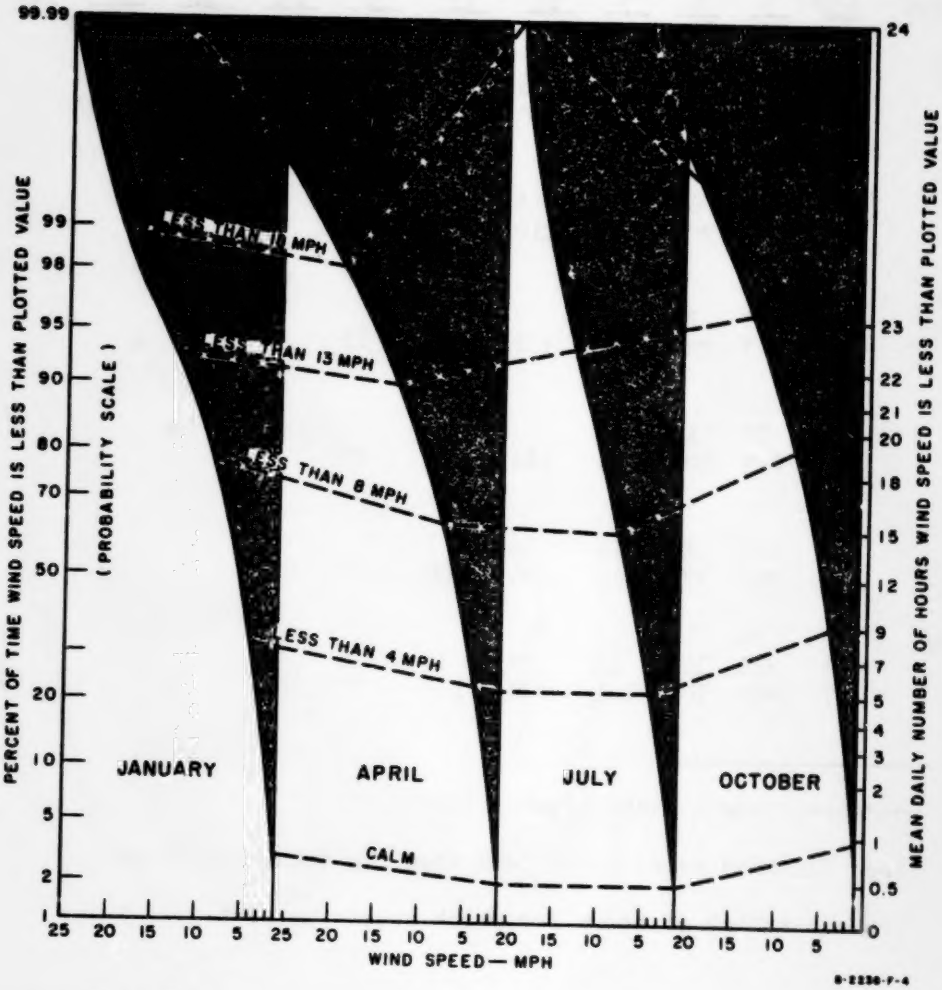


FIG. 4

MEAN DAILY WIND SPEED VARIATION BY MONTHS — FRESNO

Table III

CUMULATIVE FREQUENCY OF WIND SPEED PERSISTENCE[a]
(August, 1949 - July, 1954)

Month	SPD[b]	Number of Consecutive Hours 3	6	9	12	15	18	24	30	36	48	GR[c]
Jan	0	9										3
	3	360	117	48	26	12	2					18
	7	818	363	211	128	100	79	14	8	8		46
Mar	0	11	2									7
	3	207	62	25	11	2						16
	7	673	288	159	110	100	43					23
May	0											2
	3	107	24	7	3							12
	7	603	255	127	102	62	12					21
Jul	0											2
	3	77	12	1								9
	7	678	292	154	124	71	17					22
Sep	0											2
	3	157	42	14	4	1						15
	7	762	332	186	136	108	42	1				25
Nov	0	14	1									7
	3	321	100	43	22	15	3					18
	7	865	389	241	138	117	97	13	8	7	2	50

---

[a] Condensed from a machine tabulation.

[b] Speed (in mph) equal to or less than the tabulated value.

[c] Greatest number of hours for which speeds persisted.

Wind data based on hourly observations are almost always at a premium in any area for which a survey is being attempted. Occasionally it is possible to uncover non-serial hourly wind observations for some points in a given area of interest. For these data to be useful, some means for extending the time covered is necessary. This can be accomplished by comparison of hourly occurrences of wind for the station of incomplete record with simultaneous hourly occurrences at a station in the area for which a complete record is available. Both stations must be influenced by the same wind circulation pattern. A Weather Bureau airport station can be used as a base station. Its hourly wind data can be co-tabulated with simultaneous occurrences of wind direction at the station with incomplete data. Such a table is shown schematically in Table IV.

Table IV

CO-TABULATION OF SIMULTANEOUS WIND DIRECTION OCCURRENCES

		Station A (base station)						
		N	NNE	NE	ENE	E	etc. to 16 points	NNW
Station B	N							
	NNE							
	etc. to 16 points							
	NNW							

If there is a relationship between the wind directions at the two stations, it will be found that the tallies of simultaneous occurrences tend to be grouped with the maximum number of tallies occurring relative to one direction for Station A (long record) and another or the same direction for Station B (non-serial record). If such a relationship can be found relative to the intervals of record for Station B, it is then possible to reconstitute wind direction data at Station B for the missing data intervals. Unless a fairly tight grouping of simultaneous occurrences in wind direction is the result of the co-tabulation, any reconstitution of direction data is questionable. The usual statistical tests of variance can be applied to substantiate use of questionable reconstituted data.

The tabular or graphical comparison of occurrences of wind direction with simultaneous occurrences of smoke or haze* or of inversion height will provide additional bases for judging the conditions responsible for gross pollution accumulation and for defining adverse conditions.

2. Upper Air Data

The atmosphere's ability to disperse pollutants upward is a function of the air temperature distribution with height. Upper air data are important, therefore, in the study of air pollution problems. Unfortunately, the number and geographical distribution of upper air stations in California are limited with respect to the scale of consideration necessary even in large-scale air pollution surveys. If available data are to be put to useful application, means must be found for establishing large-scale continuity between widely separated points of measurement (such as Oakland, Santa Maria, and San Diego). Before proceeding with a discussion of methods, however, it is necessary to establish some basic concepts concerning inversion parameters.

---

* Since July 1956 such a comparative tabulation has been included in Table F (Occurrences of Weather by Wind Direction) published in Local Climatological Data, Supplement for first order Weather Bureau stations (Section III, A-2).

The upward dispersal of air pollution is suppressed whenever the lower atmosphere is stable, i.e., when warm air surmounts cool air. The vertical temperature distribution in a warm air layer of limited extent is called a temperature inversion. Air temperature increases from base to top of the inversion layer.

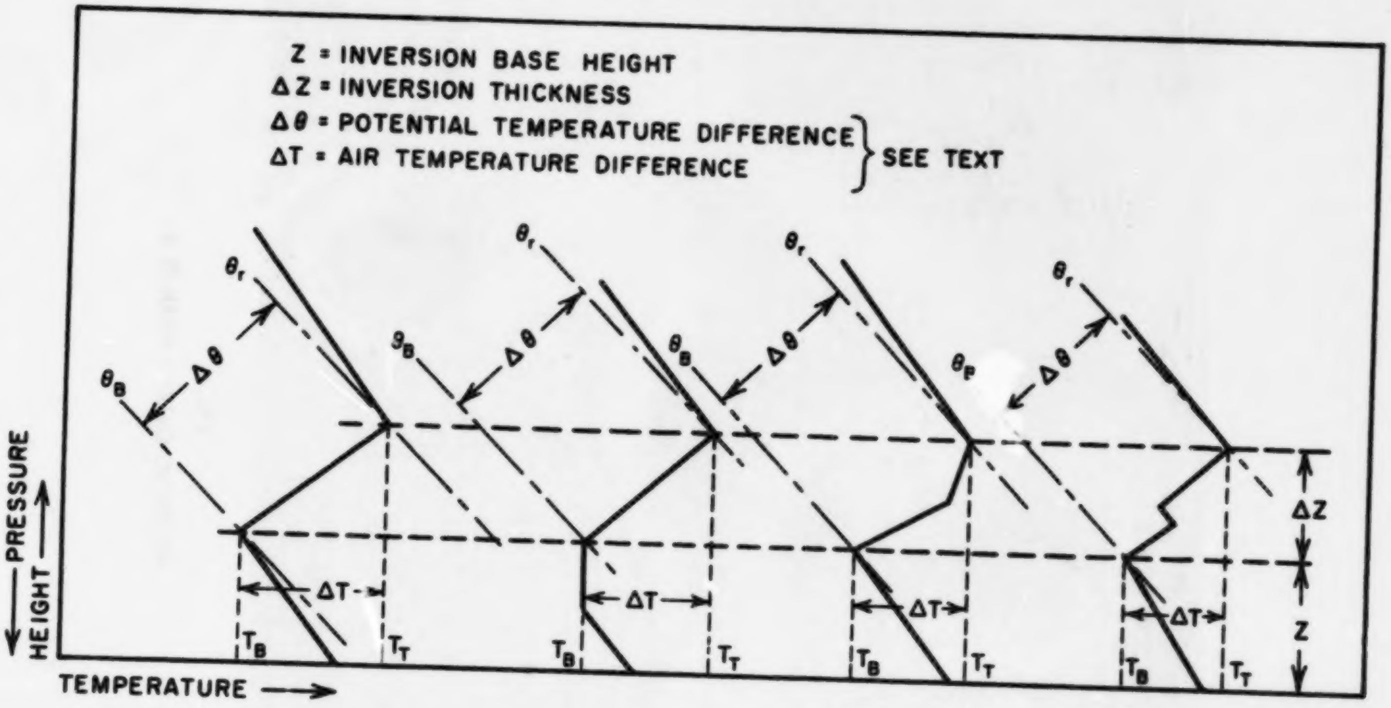
Two classes of temperature inversion occur in California. These inversions are subsidence and radiation types. Their occurrence is subject to seasonal and daily variation as well as to geographical variation. The meteorological phenomena responsible for creation of these two classes of inversion are discussed in Section V-H and I.

For the time being, it is sufficient to consider the graphical representation of inversions which results when upper air temperatures are plotted with respect to height. Figure 5 shows several configurations of subsidence-type inversions. The heavy lines show the height variation of temperature.* The inversion is that portion of the curve sloping upward to the right. The thickness of the inversion (ΔZ) is the height difference between the top and the base of the inversion. The inversion base height (Z) is the height above the earth's surface of the lowest temperature in the inversion layer. The light, dashed lines sloping upward to the left have a slope equivalent to the normal decrease of temperature with height of an ascending air parcel if the atmosphere was perfectly dry. A number of these sloping lines paralleling one another appear on upper air charts (such as in the WBAN 31-A adiabatic chart shown in Figure 6). Temperature values are assigned to each of these parallel sloping lines. These lines represent the temperature a parcel of air would have if it were displaced downward from its original level to a standard pressure level (1000 millibars) near the earth's surface. This arbitrary temperature is called the potential temperature (θ), and is a distinguishing property of the original state of an air parcel. The difference ($\Delta\theta = \theta_T - \theta_B$) between the potential temperatures at the top (θ_T) and base (θ_B) of the inversion layer** (see Figure 5),

---

* Radiation inversions are formed during night hours due to cooling of the air in contact with the earth which loses heat by radiation to the upper air. This type of inversion can be visualized from Figure 5 by considering the earth's surface to be situated at the base of the inversion as would be the case if Z in Figure 5 were equal to zero.

** Not to be confused with the air temperature difference ($\Delta T = T_T - T_B$) through the inversion layer. This criterion is used in Table VII below.


Z = INVERSION BASE HEIGHT
ΔZ = INVERSION THICKNESS
Δθ = POTENTIAL TEMPERATURE DIFFERENCE
ΔT = AIR TEMPERATURE DIFFERENCE
SEE TEXT
θ_r
θ_B
Δθ
θ_P
ΔZ
Z
ΔT
T_B
T_T
PRESSURE
HEIGHT
TEMPERATURE

A-2230-F-5

FIG. 5

SCHEMATIC CONFIGURATIONS OF SUBSIDENCE INVERSION TYPES

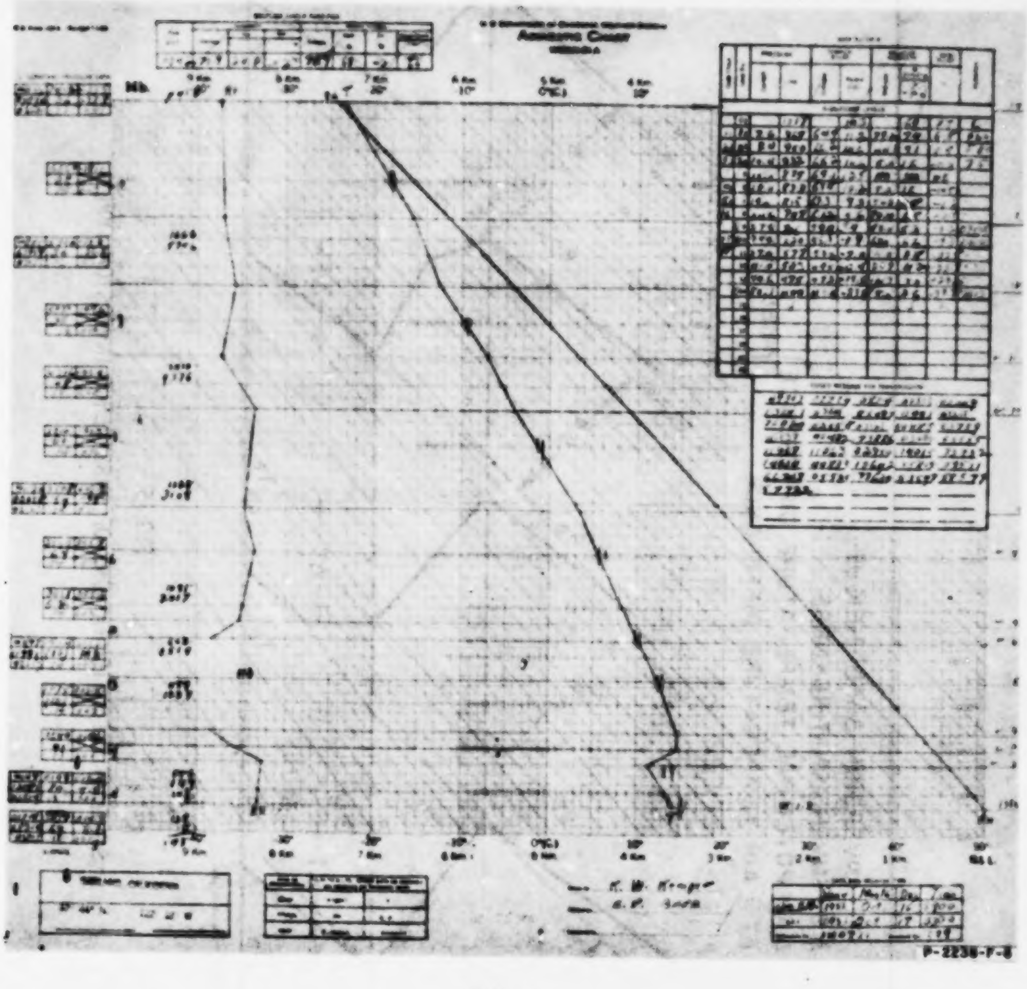


FIG. 6

ADIABATIC CHART — WBAN-31 A

divided by the thickness of the inversion layer (ΔZ) will always be a positive value greater than zero ($\Delta\theta/\Delta Z > 0$) and be a measure of the inversion stability. The larger the value of $\Delta\theta/\Delta Z$, the more capable the inversion is of resisting upward dispersion of pollutants accumulated in the air layer defined by Z, the inversion base height (Figure 5).

The adiabatic chart shown in Figure 6 and known as WBAN 31-A is the working diagram upon which upper air data are plotted. The y-axis scale shows air pressure decreasing upward according to the equation $y = p^{0.288}$ where p is the pressure in millibars. The x-axis shows two linear scales. One is air temperature in degrees Centigrade increasing to the right. The other is altitude in kilometers increasing to the left. A short scale parallel to the x-axis in the lower left part of the chart shows percent of relative humidity increasing to the right.

The data shown in Figure 6 are for the upper air conditions at Oakland on October 16, 1951 at 1900 PST. Three curves are drawn on the chart. The curve to the left shows the variation of relative humidity with decreasing air pressure (pressure altitude) and is labeled RH. The middle curve (labeled T) shows the variation of air temperature with pressure altitude. A typical subsidence inversion is indicated. The right hand curve shows the variation of air pressure with height above sea level for this sounding and is labeled PH. The lines of constant potential temperature (θ) in Absolute degrees (273°A=0°C) slope upward to the left. All of the necessary inversion parameters can be obtained from this chart.

Some information about the interaction of the three inversion parameters can be derived from a graphical manipulation of the data, although there is no precise mathematical relationship among the parameters. If inversion parameter data for a given station are plotted on graph paper using inversion base height (Z) for the x-axis and the inversion thickness (ΔZ) as the y-axis, values of the inversion stability ($\Delta\theta/\Delta Z$) spotted with respect to simultaneously occurring values of Z and ΔZ will be arrayed in a matrix of valued points. A crude relationship among the parameters can be demonstrated by drawing isolines of $\Delta\theta/\Delta Z$ on the graph. Since upper air data usually are for 7 AM and 7 PM PST* it is necessary to plot these separately using a given month's data for several consecutive years. Examples of this method of data presentation are used in support of the discussion on subsidence inversion characteristics for California in Section V-H below (see Figures 23 to 25).

Individual inversion parameters may be correlated with simultaneous occurrences of other meteorological observations such as wind direction, wind speed, or visibility to indicate conditions conducive to pollution accumulation. To accomplish this a log of hourly observations such as WBAN Form 10-A (See Section III-B-2) as well as tabulations of inversion parameters from WBAN 31-A - Adiabatic Chart (Section III-B-3) are necessary. An example of one such tabulation is shown in Table V for occurrences of visibility and inversion base height at Long Beach, California for the months of July, August, and September during 1950, 1951, and 1952.

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* Since July 1956 upper air soundings have been taken at 4 AM and 4 PM PST.

Table V

RELATIVE OCCURRENCE OF INVERSION BASE HEIGHTS AND VISIBILITY OBSERVATIONS - LONG BEACH, CALIF.[a]

	Inversion Base Height						
Visibility	101-200 meters 351-656 feet	201-400 meters 659-1312 feet	401-600 meters 1315-1968 feet	601-800 meters 1971-2624 feet	801-1000 meters 2627-3280 feet	Total	Percent Frequency
1 to 2-1/2 mi	24	16	6	2	-	48	19.8
3 to 6 mi	20	41	34	14	6	115	47.5
7 to 9 mi	-	9	26	17	8	60	24.8
10 mi	-	-	4	7	8	19	7.9
Total	44	66	70	40	22	242	100
Percent Frequency	18.2	27.3	28.9	16.5	9.1	100	

---

* July, August, September 1950-52 - 7 AM data only

Such a tabulation presents the most frequent occurrences of the variables as well as the combinations of variables.

The inversion parameters can be combined empirically and with other weather variables to provide the basis for computation of a pollution index. It is convenient to consider the influence of the inversion on air pollution by incorporating the three inversion parameters noted above $(Z, \Delta Z, \Delta\theta/\Delta Z)$ into an expression which yields a single numerical value representative of the inversion conditions. This number can represent the "intensity" of the inversion. So that large values of inversion intensity, I, will represent conditions most effective in suppressing upward dispersion of pollution an equation can be written where I is directly proportional to inversion stability, $\Delta\theta/\Delta Z$, and to potential temperature difference, $\Delta\theta$. The inversion base height, Z, which determines the volume of air beneath the inversion will be inversely proportional to the inversion intensity. As the value of Z decreases, inversion intensity (I) must increase. Thus a simple expression can be written which incorporates the above factors:

$$I = \frac{(\Delta\theta/\Delta Z)(\Delta\theta)}{(Z)} \qquad /1/$$

$$= \frac{\Delta\theta^2}{Z(\Delta Z)} \qquad /2/$$

In practice it has been found necessary to add a constant to the denominator which may be considered a "leakage factor" since there is some diffusion through the inversion.* The constant also prevents the value of I from becoming too large whenever the values of Z and ΔZ become small. Equation /2/ then becomes,

$$I = \frac{\Delta\theta^2}{3+Z\Delta Z} \qquad /3/$$

The terms Z and ΔZ are expressed in hundreds of meters (i.e., 250 meters = 2.5) and $\Delta\theta$ is expressed in degrees-Absolute (equivalent to degrees-Centigrade since only temperature difference is involved). In cases where the base of the inversion is situated at or near the earth's surface, a minimum value of 150 meters is assigned to Z and the values of ΔZ and $\Delta\theta$ are taken from the adiabatic chart where Z = 1.5 (150 meters).

Use of a single value for defining inversion conditions permits the tabulation of the frequency of a given period of days when the value of the intensity index is greater than or equal to a selected value. Such a tabulation for Santa Maria is shown in Table VI.

Table VI

FREQUENCY OF PERSISTENCE OF INVERSION INTENSITY - SANTA MARIA, CALIF.[a]

Inversion Intensity (I)	Duration of Period, Days														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5.1	8	6	5	2	2	3	2	2	2	1	0	0	0	1	2
10.1	7	5	6	2	2	5	0	1	0	0	0	1			
15.1	8	5	2	2	2	3	1	0	0	2					
20.1	7	5	3	0	2	1	2	0	0	1					
25.1	8	3	1	3	1	1	1								
30.1	5	2	3	1	0	1									
35.1	6	2	2	1											
40.1	4	1	1												

[a] May,July,Sept, Oct,Nov 1950-51, 7 AM Data Only

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* e.g., in the vicinity of mountain slopes heated by the sun.

Similar tabulations could be made of the individual inversion parameters. However, Table VI affords a composite consideration of the inversion conditions. The tabulation would be enhanced further if a significant positive correlation with pollution parameters could be demonstrated for the inversion intensity figure.

Another method of tabulating inversion data is a type used by the Bureau of Air Sanitation. In this type the actual difference in air temperature between the top and base of the inversion is used as a criterion of inversion stability. The use of the actual air temperature difference is a matter of convenience in the extraction of data for tabulation. An example of such a data tabulation is shown in Table VII for 7 AM and 7 PM soundings taken at North Island NAS, San Diego during the Octobers of 1950 through 1953 and 1955. It is a convenient form for classifying the most frequent combinations of inversion parameters on a monthly basis at a given location. From twelve such monthly summary tabulations, graphical summaries of the monthly variation of the most frequent combinations of inversion height, thickness, and temperature difference may be prepared for each station reporting upper air data.

At the present time there are four regularly reporting upper air stations on the Pacific Coast. These are located at Oakland, Santa Maria, Santa Monica, and San Diego. Historical data are available also from Long Beach and short periods of data from Merced, Auburn, and Fresno. A method of using the data from Oakland, Santa Maria, and San Diego to interpolate inversion conditions between these stations is described in Appendix A and discussed in Section V-H.

The use of inversion data for the calculation of a pollution index has been applied to the Los Angeles area. The index is called the "smog index" and has been used with some success in that area. The empirical equation takes the form,

$$S = \frac{10(T+10)}{RW} \sqrt{\frac{I}{V}} \qquad /4/$$

where S is the index, T is the difference between the daily mean temperature and the normal mean temperature for the day in degrees F, R is the relative humidity at noon in percent, W is the total 24-hr wind movement in miles, I is the inversion intensity (calculated according to Equation /3/ above) and V is the visibility at noon in miles.

Another type of empirical pollution index equation was used in connection with the air pollution study at Leicester in England. This equation is of the form,

$$P = 0.552 + \frac{0.14}{\sqrt{u}}(25.5 + L) \qquad /5/$$

where P is the pollution density, u is the mean wind speed in mph, and L is the lapse rate in °F/3000 ft. The constants are empirically determined with the aid of air pollution measurements.

Table VII

FREQUENCY OF OCCURRENCE OF TEMPERATURE INVERSION PARAMETERS[a]

0700 PST Observations

Height of Inversion Base, ft	Frequency	Inversion Layer									
		Temperature Difference(°C) Top Minus Base				Thickness (ft) Height of Top Minus Height of Base					
		0-3	4-6	7-9	9	0-500	501-1000	1001-1500	1501-2000	2001-2500	2500
Surface(24)	37	5	11	14	7	3	6	9	9	4	6
25-500	10	1	1	3	5	0	3	4	0	1	2
501-1000	14	0	5	2	7	1	4	1	5	0	3
1001-1500	24	1	0	7	16	2	4	7	7	3	1
1501-2000	22	1	1	8	12	1	3	11	3	4	0
2001-2500	16	3	2	6	5	3	3	5	2	2	1
2501-3000	6	2	1	1	2	1	2	0	1	1	1
3001-3500	7	3	2	2	0	0	3	1	3	0	0
3501-5000	8	5	2	1	0	4	2	1	1	0	0
None	7										
Missing	4										
Total	155	21	25	44	54	15	30	39	31	15	14
1900 PST Observations											
Surface(24)	25	13	7	3	2	6	3	7	5	2	2
25-500	13	1	2	7	3	1	2	4	3	2	1
501-1000	29	3	10	8	8	2	4	8	13	1	1
1001-1500	35	7	9	11	8	6	4	9	11	3	2
1501-2000	16	3	4	5	4	3	1	3	3	3	3
2001-2500	11	3	1	7	0	0	3	3	1	0	4
2501-3000	5	0	4	0	1	1	1	1	1	1	0
3001-3500	4	2	1	1	0	2	1	1	0	0	0
3501-5000	3	2	1	0	0	1	1	1	0	0	0
None	10										
Missing	4										
Total	155	34	39	42	26	22	20	37	37	12	13

[a] San Diego - October 1950-53, and 1955.

Similar equations can be developed for other areas providing sufficient pollution data are available for evaluation of the empirical constants. It is not likely that these types of equations are universally applicable.

V California Air Pollution Climatography

A. Introduction

The complete, quantitative description of climate is accomplished by consideration of the characteristics exhibited by absolute extremes and frequencies of given departures from long-term averages of observed weather elements. This is the usual basis for a comparative, geographic climatography. Special climatographies which consider the effects or interaction of weather on certain activities of man are also useful. Such climatographies may consider a limited number of applicable weather elements which are standardly observed as well as a variety of atmospherically related variables requiring special measurement and interpretation.

This special climatography is aimed principally toward demonstrating the practical application of climate data to the definition of climatically coherent regions as far as the presence or absence of weather elements affecting air pollution are concerned. The demarcation of these climatically coherent regions rests with California's unusual distribution of pronounced mountainous structures and a coastal boundary of considerable latitude.

The presence or absence of a general level of pollution as exhibited by the long-term trend of visibility data at a given station will be of interest for some regions. This pollution-visibility relationship cannot, however, be classed as an indicator of spatial similarity, and will represent the only notice that will be taken of possible correlations between air pollution and climatic elements.*

B. Discussion of Methods

There are many ways in which climatic data and combined or derived climatic quantities may be used to demonstrate the climatic coherency of a region. In the air pollution climate description to follow, regional similarity is demonstrated first, by a coarse longitudinal partitioning of the state using the derived climatic quantity known as continentality,** and second, with seasonally representative, monthly means of the daily range of temperature derived from long-term U.S. Weather Bureau records. Regional similarities are examined also with the aid of mean wind circulation patterns and mean wind movement.*

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* An example of how such correlations may be accomplished is represented in a report of the Air Pollution Foundation (2) issued in connection with scientific studies of Los Angeles smog.

** A numerical index obtained from an empirical equation developed by V. Conrad involving the annual range of temperature and the latitude of the recording station (3).

The spatial distribution of atmospheric stability as represented by the semi-permanent subsidence inversion is defined through the statistical manipulation of radiosonde data (upper air temperature and pressure) from three coastal stations. A crude attempt is made to extrapolate the inversion height from coastal areas to the central interior valley.

Whenever possible, graphical rather than tabular forms of climatic data are used. This will enable the reader to follow the interpretive discussions more easily.

The only derived climatic element other than the continentality index used in this description is the mean "inversion intensity coefficient". This is an empirical number calculated from an equation which provides a numerical representation of the ability of a temperature inversion to suppress vertical dispersion of air pollution trapped below it.

In conformity with usual practice, brief descriptions are given of the geographic and physiographic aspects of California, and of the climatic-synoptic effects of characteristic weather patterns.

C. Geographical and Physiographical Descriptions

The most distinguishing geographical features of California are its long Pacific coastline (1264 mi between latitude 32°30' and 42°N); its narrow east-west extent (various 150 to 350 mi) compared to its medial north-south length (780 mi); and its total area (158,693 mi including inland water areas totaling 1953 sq mi).

California's main physiographical features (see Figure 7) are two principal ranges of mountains which run almost the full length of the state, one along the coast and the other along the eastern border.

The Coast Ranges are composed of many indistinct mountain chains broken into large numbers of ridges and spurs by small valleys. The western slopes rise abruptly from the sea in some places, and from a narrow coastal plain in others. The only significant break in the Coast Ranges is through the Golden Gate and Carquinez Strait. Range altitude varies from just under 1000 ft to 8000 ft, being highest in the north

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* Sometimes referred to as the "run of the wind," which simply is the product of the mean wind speed (weekly, monthly, or yearly) and the equivalent number of hours of wind. These results can be resolved to standard wind directions provided the data are in hourly form by directions. Daily wind movement usually cannot be obtained unless special totalizing anemometers are used or available at the reporting stations. However, the mean wind speed for a specified period (week or month) can be resolved into a 24-hr wind movement figure.

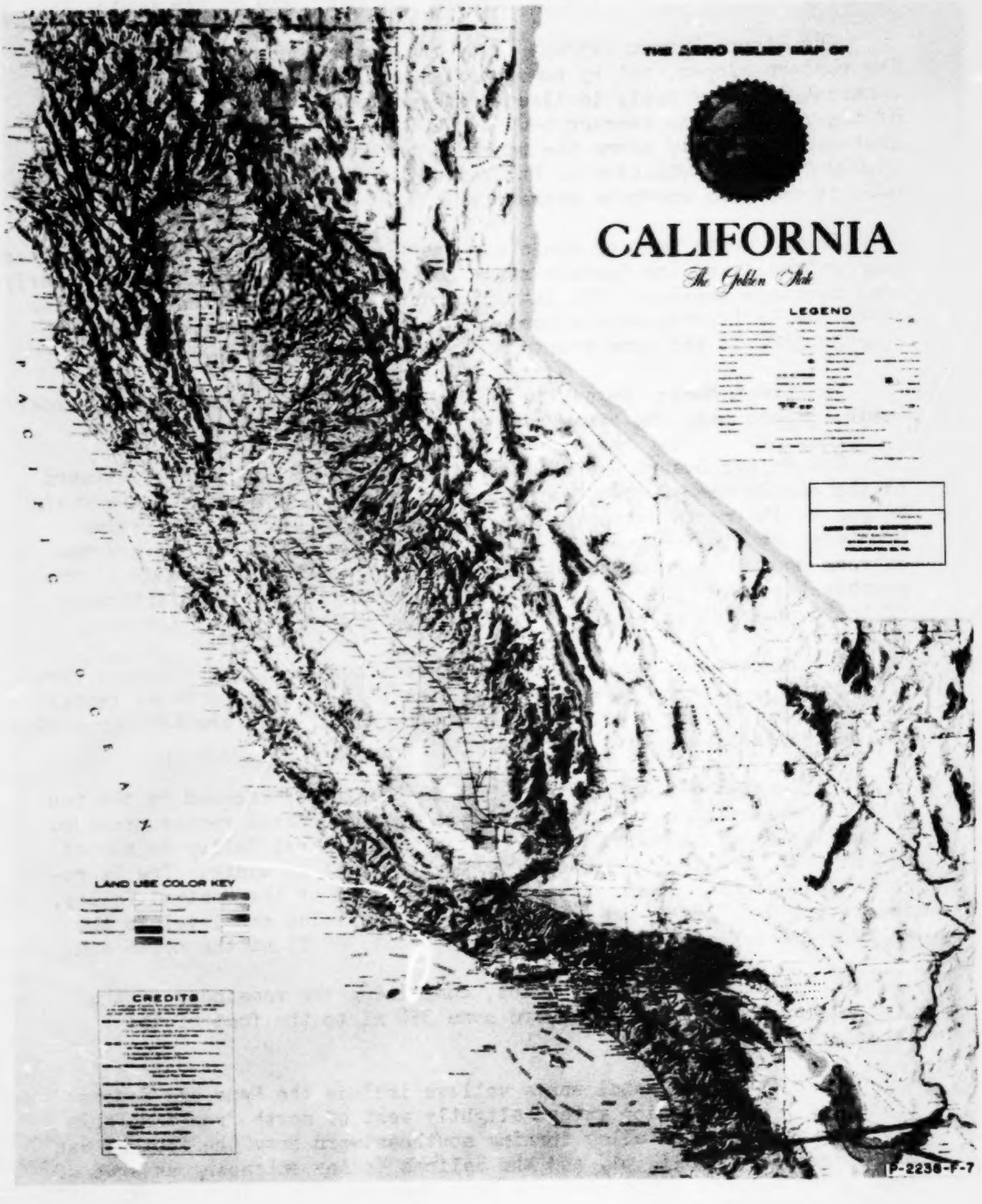
THE AERO RELIEF MAP OF
CALIFORNIA
The Golden State
LEGEND
P A C I F I C O C E A N
LAND USE COLOR KEY
CREDITS
P-2238-F-7

FIG. 7

(Rocky Point) and south (Santa Barbara County) parts of the state.

The Sierra Nevada extends along the eastern boundary of the state. The western slopes, cut by numerous valleys, are broad and gentle in contrast to the steeply inclined eastern slopes. At the northern end of the range, peaks average 6000 to 7000 ft. The average altitude increases gradually along the range to the south, reach a maximum near 15,000 ft in the vicinity of Mt. Whitney, and diminish to an average 6000 ft near the southern extremity.

In the north part of the state the Klamath mountains and the southernmost extremity of the Cascade range form a rugged though not particularly high mountain complex. The latter borders the Modoc plateau which lies along the California-Nevada border. The altitude of the region is roughly 4500 ft and some mountain peaks are over 7500 ft.

The Great Basin ranges lie between the Sierra and the Nevada border south of Mono Lake and are separated by sharp arid valleys.

The Mojave Desert extends from the Arizona-Nevada border westward to the confluence of the Sierra and Coast Ranges, merges into the Basin Ranges on its north extremity, and terminates at the San Bernardino Mountains at its southwestern margin. The Colorado Desert covers the extreme southeastern corner of the state. The Salton Sea basin in the southeastern section of the Coachella-Imperial trough is an extension of the depression forming the Gulf of Lower California.

The Transverse Ranges are an east-west system in the southern part of the state. The Los Angeles Basin lies to the south of these ranges and reaches from the coast eastward to the gap between the San Bernardino and San Jacinto mountains.

The Central Valley of California is completely encased by the two main range systems except for the break in the coastal ranges provided by the system of bays at San Francisco. The Central Valley is almost 500 mi long, and the valley floor averages 45 mi in width. The Sacramento Valley which comprises the northern third of the Central Valley, is about 150 mi long, and rises from slightly below sea level in the delta area east of Carquinez Strait to about 300 ft at the north end.

The larger San Joaquin Valley, comprising the remainder of the Central Valley, extends southward some 350 mi to the foot of the Tehachapi mountains.

The principal coastal range valleys include the Napa and Sonoma (Petaluma) Valleys which extend slightly west of north from San Pablo Bay; the Santa Clara Valley running southeastward from the foot of San Francisco Bay some 150 mi, and the Salinas Valley embracing an area of 4200 sq mi extends south eastward from Monterey Bay. In Southern California valleys of the Santa Maria, Santa Ynez, and the Santa Clara rivers penetrate the mountains directly from the coastline.*

D. Summary of Climatic-Synoptic Aspects

In addition to the extensive effects which the physiographic features of California exert on the distribution of climates within its boundaries, are the effects created as a result of the state's considerable latitudinal extent and its position on the west coast of a continent.

The latitudinal extent enables a broad spectrum of weather conditions, varying from sub-tropical in the extreme south to sub-temperature in the extreme north, to exercise control of climatic distributions.

The west coastal position of the state provides a considerable maritime influence on the climate and also permits the semi-permanent high pressure pattern over the eastern Pacific to exert a dominating influence. This influence achieves two remarkable effects that are dynamic in character. Due to the mean summer position of the Pacific high pressure cell to the west of California (the center oscillates from 30° to 40°N and 140° and 150°W) a northwesterly direction is imparted to the coastal winds between about Cape Blanco in the north and Point Conception in the south. The wind causes a mass transport of surface water away from the coast which results in the upwelling of cold water (7). This mechanism is most pronounced north of San Francisco's Golden Gate and to a lesser extent between Point Sur and Point Conception (7), and is reponsible for pronounced cooling of air transported over the coastal waters.

Another dynamic aspect related to the anti-cylconic circulation of air around the Pacific High cell is the large-scale subsidence of air at altitudes above the ocean-cooled, surface layer. This subsiding air becomes heated by compression in moving from levels of low to levels of high atmospheric pressure. The mechanism provides a layer of warm air which surmounts the surface layer cooled by contact with the ocean water, thus producing a stable stratification referred to as the subsidence inversion.

The size and circulation strength of the Pacific high reaches a maximum in August. During September, October, and November the Pacific high is moved southeastward from its summer position by storms advancing across the north central Pacific. It is during this three-month period when "coupling" between the Pacific high cell and continental high cells may occur. Little wind movement accompanied by low-altitude temperature inversions is apt to prevail at this time over central California. Lower average inversion heights are also produced in southern California during the fall season. This is due to the occurrence of radiation type inversions.

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* The foregoing physiographical description was summarized from Tech. Bull. No. 158 of the California Division of Mines (6).

During the winter and early spring seasons storm activity or pronounced off-coast wind patterns are the principal synoptic occurrences affecting climatic patterns. Except for anomalous synoptic occurrences, the winter and spring climates do not favor air pollution accumulations except where prominent topographical features provide shelter against wind movement. Central portions of the great Central Valley exhibit such an effect during the winter months. Low ground fogs may persist for several days at a time due to temperature inversions created by nocturnal cooling of land surface in the absence of appreciable air movement.

E. Distribution of Climatic Factors

Before different areas in California are defined climatically from the viewpoint of air pollution potential, consideration should be given to the geographic and physiographic aspects which serve as controlling climatic factors.

Because of the effect a continental land mass has on limiting the climatic influence of maritime atmospheric conditions, it is of fundamental interest to understand the climatic differences between the coastal and interior parts of the state. Also because of the latitudinal extent of California, climatic differences should be reflected between the north and south parts.

The most singular over-all effect of the land surface on the gross climatic distribution is revealed by the increased annual range of temperature at interior stations compared to that at coastal stations. There is also a physical correlation between annual temperature range and the latitude of a station except in the immediate vicinity of maritime coastlines. The average daily range of temperature considered on a monthly basis can be used to obtain a coarse climatic partitioning of the state and to reveal in a general way the seasonal interplay of continental and maritime influences.

As a further refinement of the gross distribution of climate, those climatic elements related to air pollution can be interpreted with respect to the distribution of the several coastal plains, valleys, basins, and plateaus to disclose climatic differences which establish relative degrees of air pollution potential.

Physiographic details which exert influence on the climate of an area are called climatic factors. In most of California the spatial variation of climate is heavily dependent upon the extent to which the various mountain ranges or gaps hinder or aid maritime influence on the interior. The orientation of the various mountain ranges establishes the necessity of considering climatic entities in terms of the disposition of valleys and other mountain bounded areas.

F. Gross Distribution of Climate Based on Temperature Range

When the derived climatic quantity known as the continentality index* is plotted on a map for a number of stations and subjected to analysis by drawing lines of constant continentality, a general picture of the gross distribution of climate is obtained. The result of one analysis of this sort (8) is shown in Figure 8 for the state of California. It is obvious that the maritime influence decreases sharply with distance toward the interior. The 30 percent continentality isoline may be chosen as the effective limit of maritime influence on the climate. The map of Figure 8 shows that the 30 percent isoline roughly bisects the northern extremity of the Sacramento Valley; is deflected eastward slightly in the Southern Sacramento Valley by the influx of maritime air through the Golden Gate; continues its meridional direction along the western part of the San Joaquin Valley; is deflected eastward along the Transverse Ranges in Southern California; and continues its meridional direction along the principal ridges of the Peninsular Ranges through Riverside and San Diego Counties. The effect of geographic latitude, missing in the areas under direct or indirect maritime influence, is exhibited in the extreme southeast interior. This rough climatic partitioning based on the distribution of annual temperature range provides a first approximation of the climatic differences characterizing various parts of the state. Singular emphasis is placed on the continentality of the Southeast Desert and Great Basin Regions lying east of the Sierra Nevada and north and east of the Transverse and Peninsular Ranges in the south part.

Further understanding of the gross climate distribution can be noted by considering the average daily temperature range by months based on long-term data. The state-wide distribution of average daily temperature range is shown in the maps of Figure 9 for the mid-season months of January, April, July, and October.

A large daily range is shown for the northeast corner of the state in July and October and to a lesser degree in January and April. In the latter months extensive cloud cover and windiness tend to lower the average daily maximum temperature over this northeastern region and is a typical seasonal aspect. Thus, the Northeast Plateau region comprising Modoc County and parts of Siskiyou, Shasta, and Lassen counties appears to be a climatically coherent region.

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* Calculated from an empirical equation:

$$K = 1.7A/\sin(\gamma + 10^\circ) - 14$$

where A is the difference between the mean temperatures of the warmest and coldest months and γ is the geographic latitude at a given station (2). The index is a percentage number expressing the degree to which the land surface affects the climatic element of temperature.

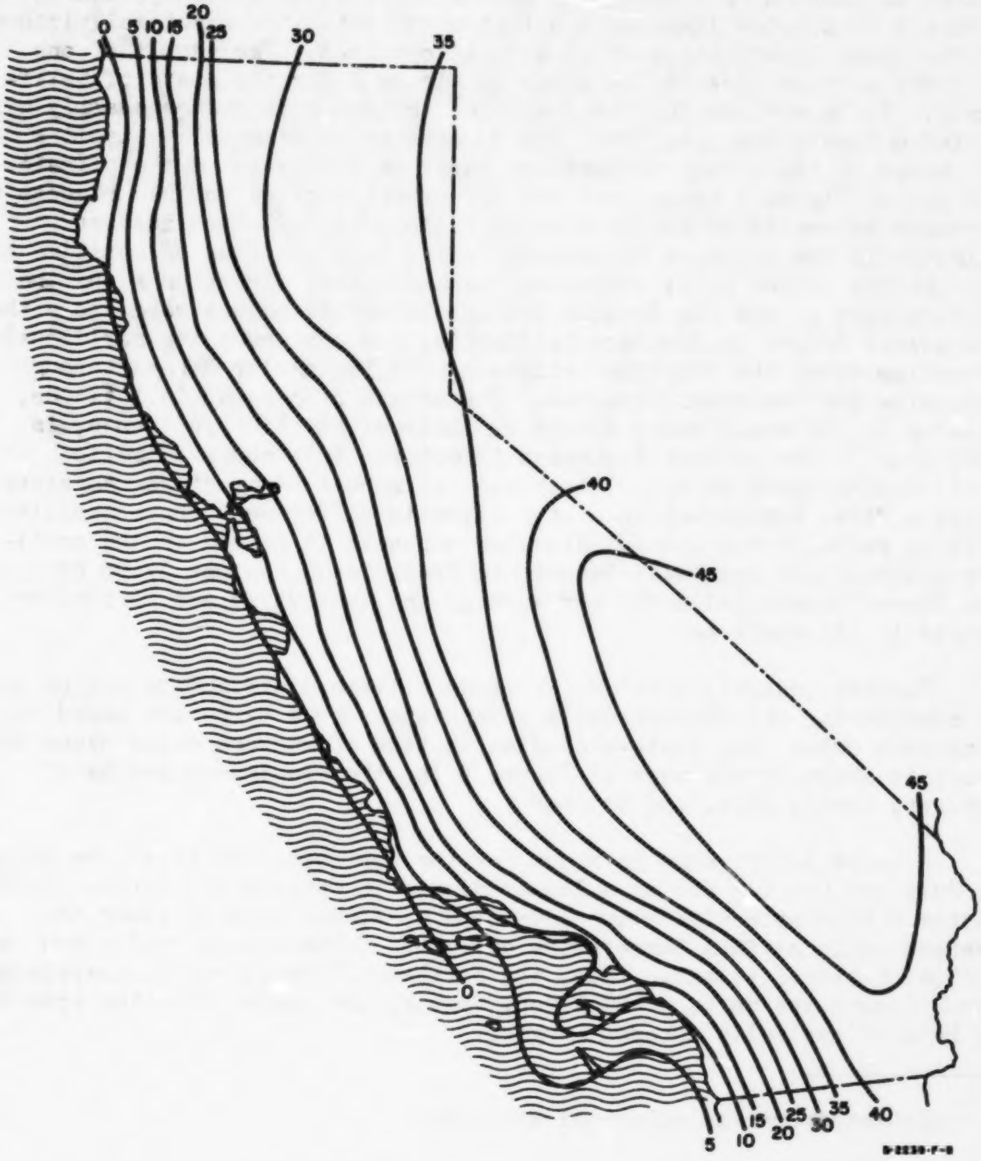
0
5
10
15
20
25
30
35
40
45
45
0
5
10
15
20
25
30
35
40

FIG. 8

DISTRIBUTION OF ISOLINES OF PERCENT CONTINENTALITY

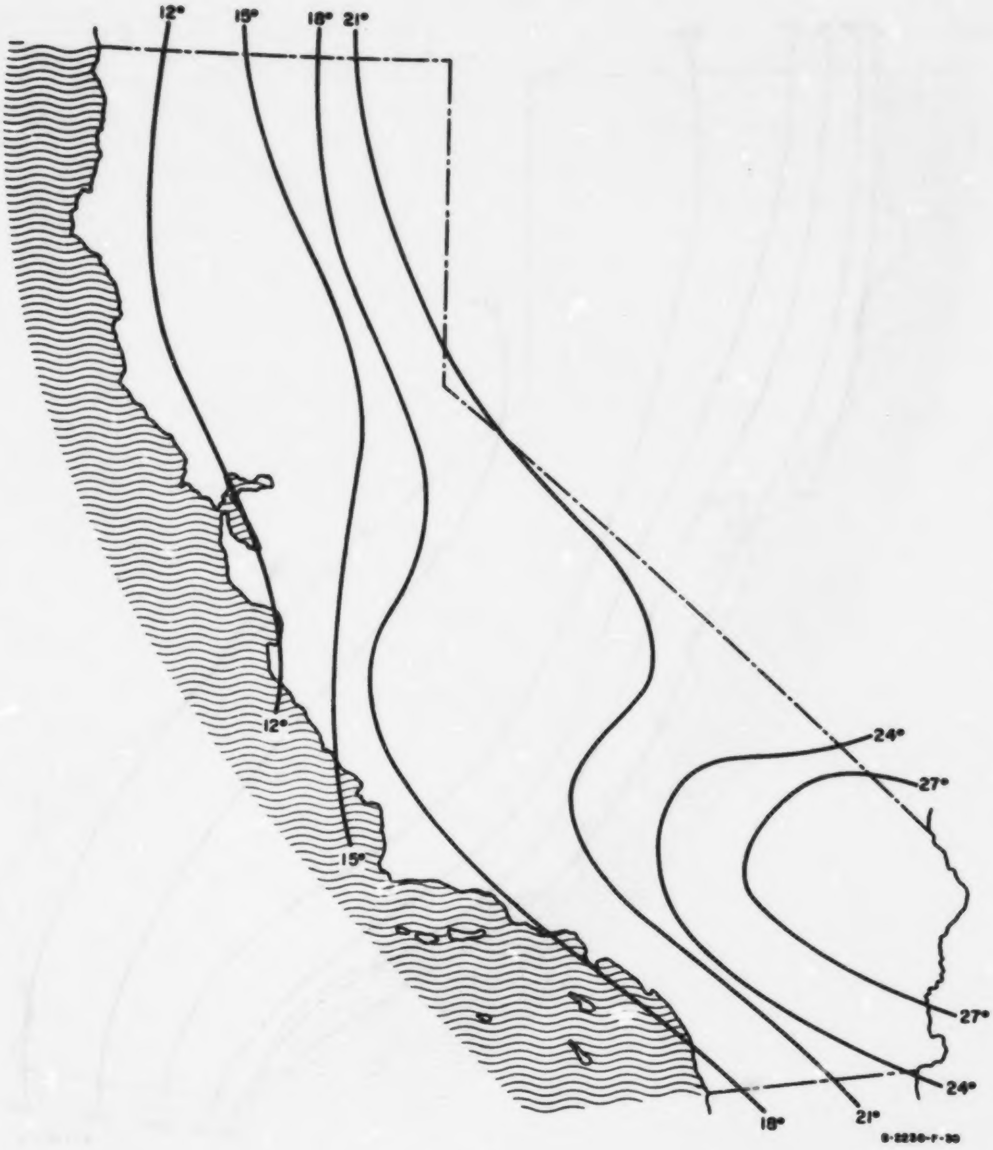
12°
15°
18°
21°
12°
15°
24°
27°
27°
24°
18°
21°
8-2230-F-30

FIG. 9(a)

AVERAGE DAILY TEMPERATURE RANGE
(JANUARY)

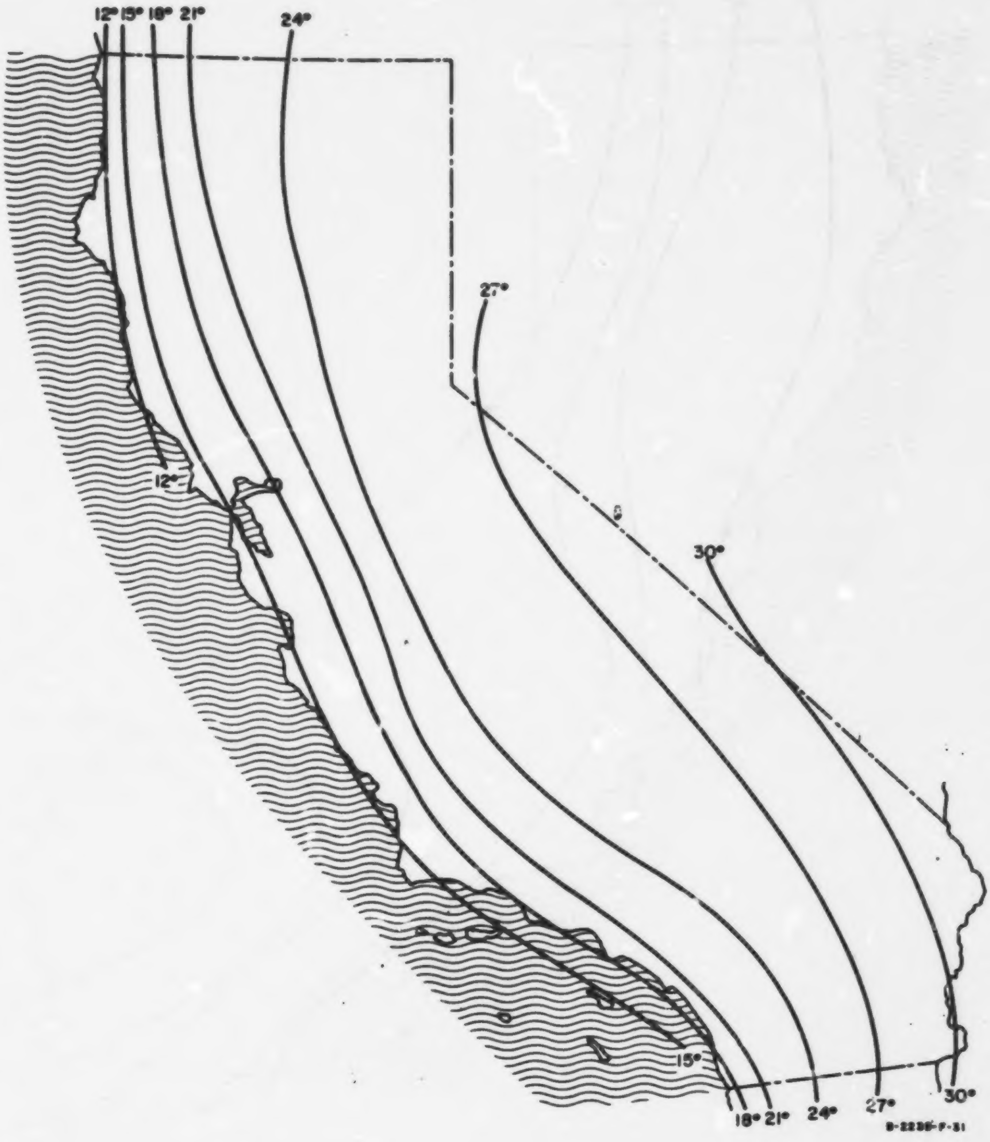
12°
15°
18°
21°
24°
27°
12°
30°
15°
18°
21°
24°
27°
30°
B-2236-F-31

FIG. 9(b)

AVERAGE DAILY TEMPERATURE RANGE
(APRIL)

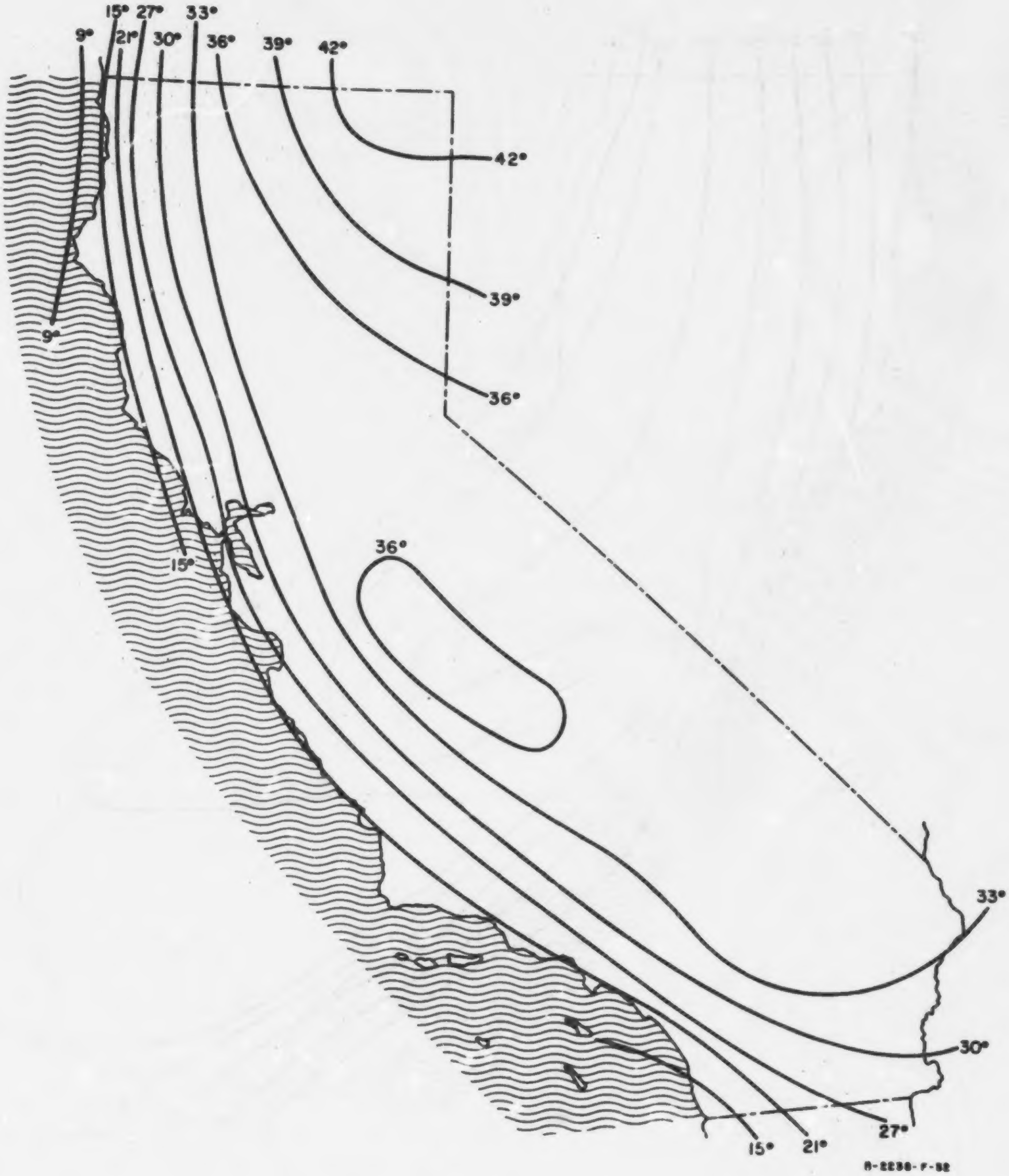
15°
27°
33°
9°
21°
30°
36°
39°
42°
42°
39°
9°
36°
36°
15°
33°
30°
27°
15°
21°
A-2238-F-82

FIG. 9(c)

AVERAGE DAILY TEMPERATURE RANGE
(JULY)

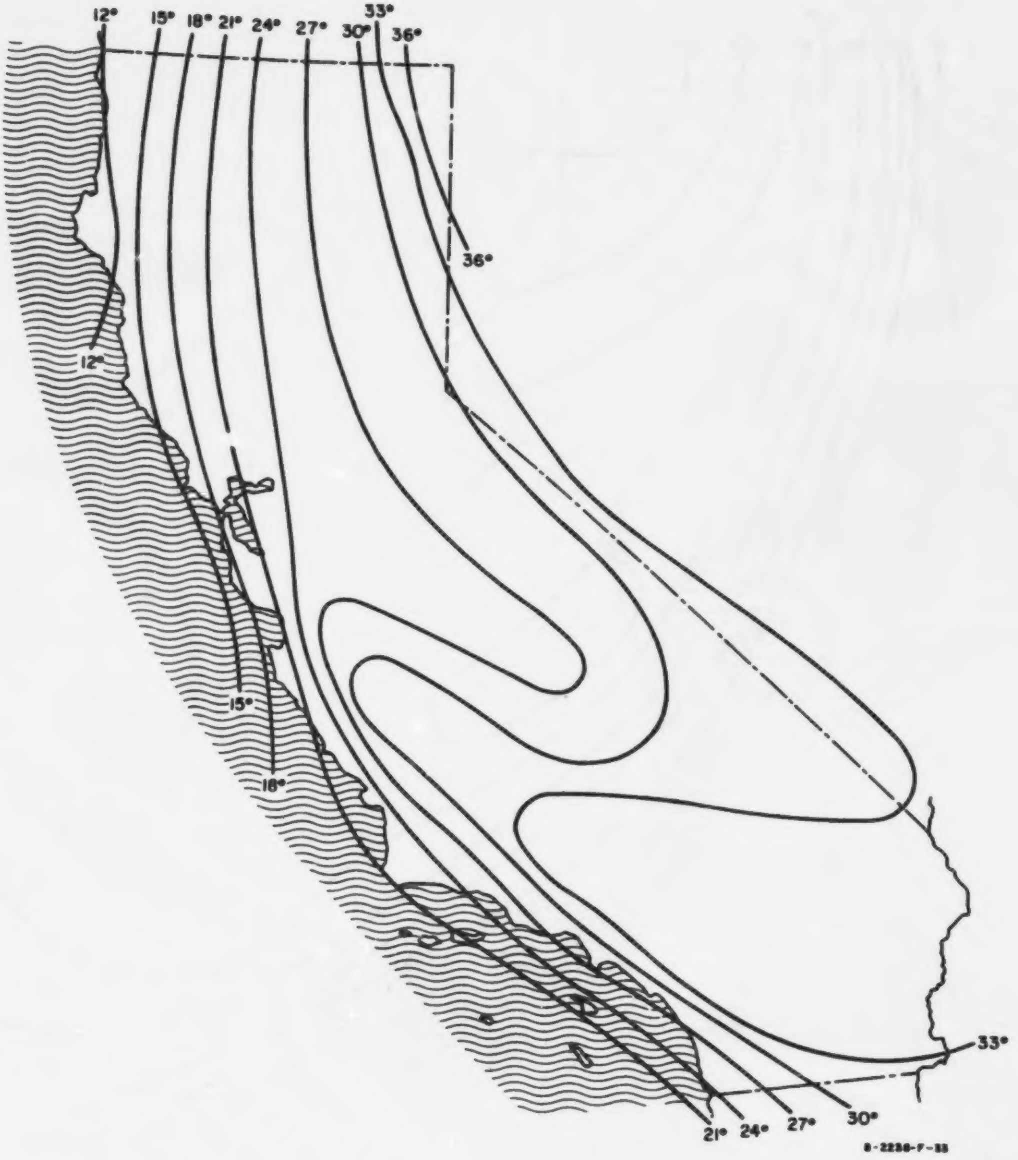
12°
15°
18°
21°
24°
27°
30°
33°
36°
36°
12°
15°
18°
33°
21°
24°
27°
30°
8-2238-F-33

FIG. 9(d)

AVERAGE DAILY TEMPERATURE RANGE
(OCTOBER)

A feature common to the maps for October and January and dominating the southeastern Great Basin and Desert region of the state is the singularly large daily temperature range. Since these are fall and winter months, one conclusion is that the large daily range is the combined result of the absence of cloudiness and the geographic latitude of the region. The lack of a large daily range over the desert region in April is related to the windy conditions characteristic of this month. Windiness prevents the accumulation of heat in the land surface by a process of forced convection. The lowered daily range in April also may be a delayed reflection of the winter-time cooling of the continent. In July a daily range greater than 33°F characterizes the region and is limited by the mountainous boundaries to the south. A rough basis is provided for classing this region a climatic entity as far as temperature range is concerned.

A similarly large daily range dominates the central and southern San Joaquin Valley in July. In October this daily range pattern undergoes distortion favoring retention of a relatively large range in the extreme southern and southwestern parts, while the daily range is suppressed in the northern and east central parts. Compared to the more or less uniform distribution of isotherms in the Sacramento Valley, the distribution in the San Joaquin Valley indicates that the two regions differ climatically even though part of the same physiographic entity. This climatic separateness is suggested also in Figure 8 by distortion in the continentality isolines over the southern Sacramento Valley due to penetration of the maritime influence.

Some indications of the gross climate distribution are shown by the relative distributions of annual and average daily temperature ranges. In addition, contrasts are shown which suggest that the Northeast Plateau and the Southeast Desert and Great Basin Regions are climatic as well as physiographic entities.

Further consideration of other climatic elements appears necessary to establish the climatic separateness of the Sacramento and San Joaquin Valleys and to reveal the climatic character of the coastal regions. Use can be made of climatic elements and derived climatic quantities which experience has shown are related to air pollution.

G. Gross Circulation of Surface Winds

The surface wind is one climatic element related to the air pollution potential of the climatic region it characterizes. The natural removal of air pollutants from their source regions is assisted or curtailed by the presence or absence of effective wind circulation. Under conditions of exceptional atmospheric stability the latter condition may be accentuated.

Wind is generated by large-scale atmospheric pressure differences. These differences result from daily pressure variations created by atmospheric pressure patterns and by temperature contrast, such as between the sea coast and interior valleys. Stagnation of air near the ground results from the lack of sufficient pressure difference or temperature contrast. Local circulation of air resulting in the recirculation of pollution may be produced.

The circulation of the wind can be represented on a mean monthly basis by a spatial comparison of the predominant wind directions for a number of stations. Such a comparison will usually reflect the conditions imposed by terrain features. The coastal ranges, for example, exercise considerable control over the penetration of on-shore winds to the interior and contribute to the boundary conditions for wind flow in the Central Valleys. The Transverse Ranges and the Peninsular Ranges in the south part of the state perform a similar boundary function separating the Los Angeles Basin and South Coastal area wind patterns from those of the southeastern Desert.

Historical wind data from 61 active and currently nonactive stations located throughout California have been analyzed to disclose the predominant wind direction at each station. This was accomplished for the midseason months of January, April, July, and October. Although the data reflect the most frequent directions occurring at each station, it should be pointed out that in many cases the second most frequent wind direction occurred almost as often as the most frequent. At stations where channelization of the wind by terrain features is a characteristic, the second most frequent direction was opposite from that of the most frequent. This was especially true in the month of January for the Central Valley Stations. The wind direction data* were plotted on maps as arrows which fly with the wind, and were subjected to streamline analysis. This demonstrates the mean predominant wind circulation during each of the seasonally characteristic months. These maps are shown in Figures 10 through 13.

Figure 10 shows the streamline analysis for January. The analysis illustrates one singular aspect which is typical of the winter season. Due to the seasonal reversal in temperature contrast between the coastline and the interior (land colder than the ocean) surface air flows seaward, principally from the Central Valley through the gap in the Coast Ranges provided by San Francisco Bay. This is the most predominant circulation. Also evident in the original data for Central Valley stations was the fact that up-valley wind directions were usually the second most frequent directions. This was true, both of the Sacramento and the San Joaquin Valleys and is a reflection that the temperature contrast favoring seaward flow of air is subject to interruption. When this occurs up-valley flow is temporarily re-established. Subsidiary airflows to seaward from coastal plains, valleys, and basins are not involved with the predominant outflow from the Central Valley (with the exception of the

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* Presented with the second most frequent wind directions, average 24-hr wind movement, and percent frequency of winds less than 4 mph as Appendix B.

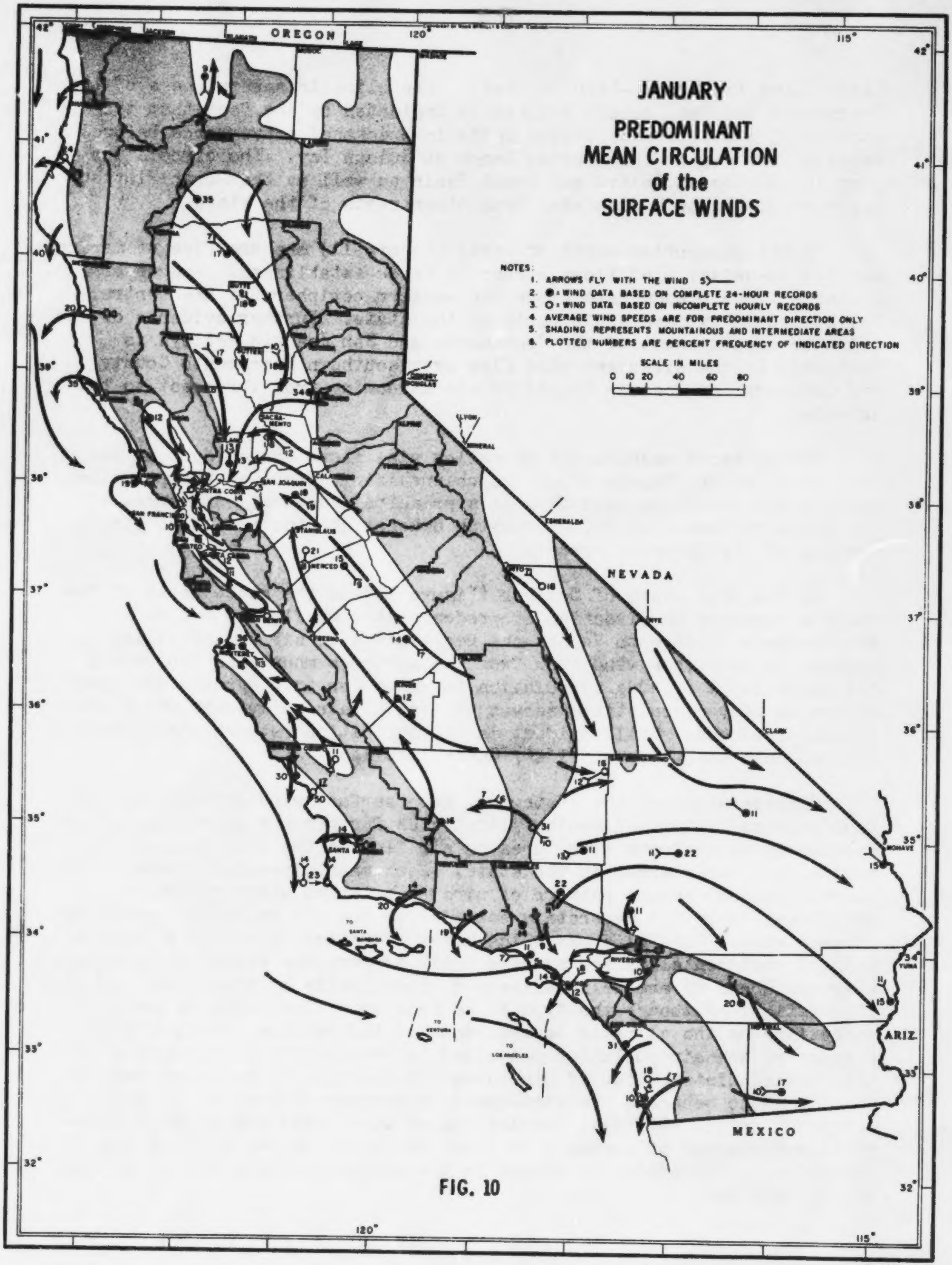

JANUARY
PREDOMINANT
MEAN CIRCULATION
of the
SURFACE WINDS
NOTES:
1. ARROWS FLY WITH THE WIND 5
2. ● = WIND DATA BASED ON COMPLETE 24-HOUR RECORDS
3. ○ = WIND DATA BASED ON INCOMPLETE HOURLY RECORDS
4. AVERAGE WIND SPEEDS ARE FOR PREDOMINANT DIRECTION ONLY
5. SHADING REPRESENTS MOUNTAINOUS AND INTERMEDIATE AREAS
6. PLOTTED NUMBERS ARE PERCENT FREQUENCY OF INDICATED DIRECTION
SCALE IN MILES
0 10 20 40 60 80
OREGON
NEVADA
MEXICO
ARIZ.
SACRAMENTO
SAN JOAQUIN
CONTRA COSTA
SAN FRANCISCO
STANISLAUS
MERCED
FRESNO
MONTEREY
SANTA BARBARA
RIVERSIDE
MOHAVE
YUMA
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°

FIG. 10

C-2238-F-10

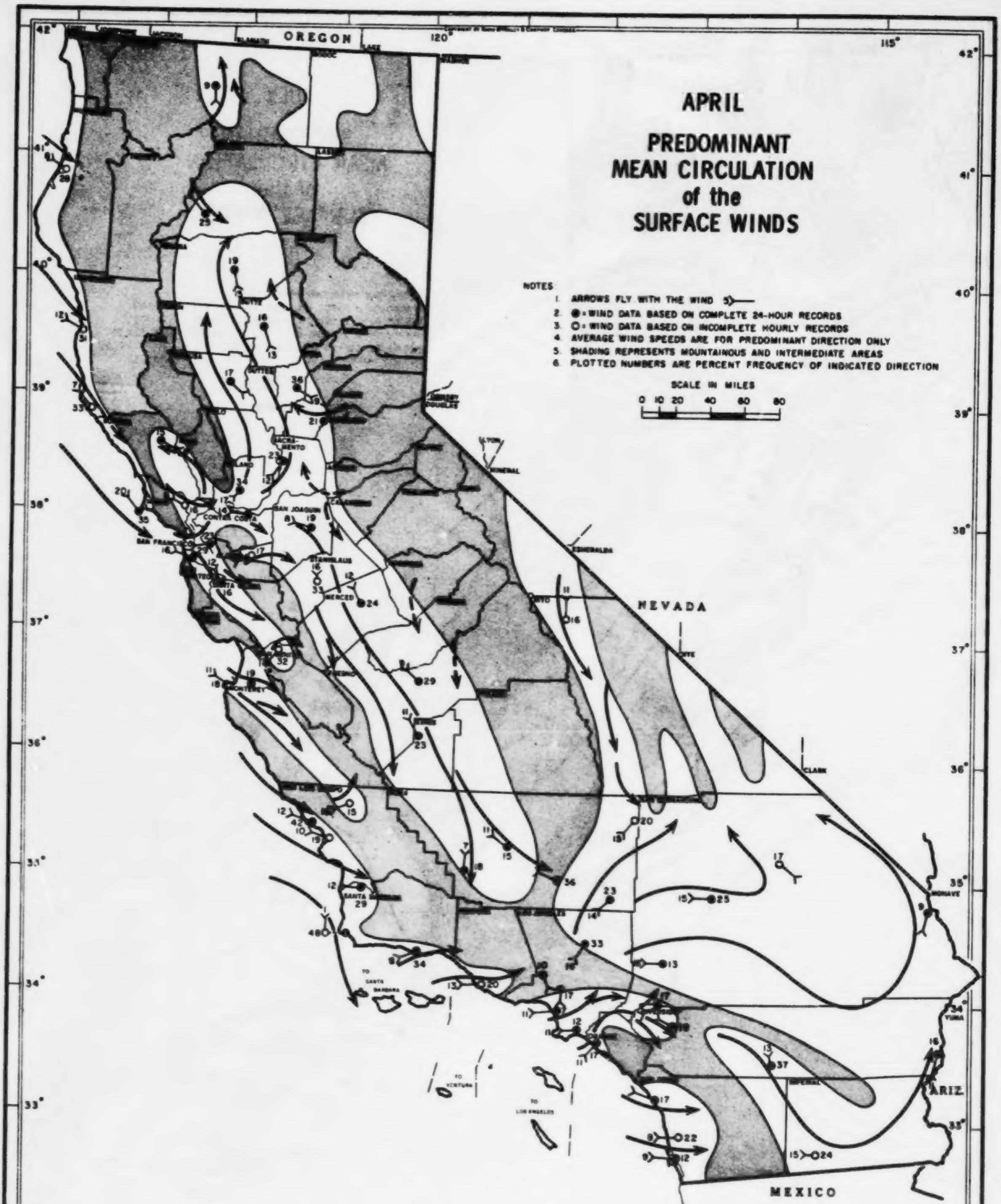
Santa Clara and Sonoma-Napa Valleys). The climatic separateness of the Sacramento and San Joaquin Valleys is indicated by the fact that the outflow of air from each valley meets in a zone of convergence before entering the gap in the Coastal Range at Suisun Bay. The circulation over the Southeast Desert and Great Basin as well as the North Plateau regions appears to be isolated from other parts of the state.

By the mid-spring month of April (Figure 11) onshore flow of marine air and up-valley wind flows appear to be re-established. Traces of drainage flows predominate along the eastern periphery of the Central Valley and in extreme south parts of the state. Further evidence of the climatic separateness of the Sacramento and San Joaquin Valleys is indicated by the divergent wind flow over southern Sacramento County and northern San Joaquin County of air streaming from the coast to the interior.

Strengthened onshore and up-valley wind flows are evident in the July circulation (Figure 12). The channelizing effect of the principal valleys and basins on wind flow is a principal feature. All areas of the state reflect wind patterns which demonstrate the effect of strong heating of the interior areas.

In the fall month of October (Figure 13) in the north parts of the state a reversal in direction of predominant wind flow is evident. In the Northern Sacramento Valley the penetration of air up the valley is opposed by downslope wind flow from the northern mountains indicating the possibility of eddy circulation in Butte County. Dynamic air stagnation in eddy circulations serves to concentrate pollutants which are locally produced. Still evident is the opposition between wind circulations into the upper and lower Central Valley.

Consideration of the statewide, mean surface wind circulation for four seasonally typical months illustrates further the pronounced effect exerted by mountainous structures on air flow in the principal valleys, basins, and other areas in the state. Each mountain-bounded area displays a typical season pattern of wind circulation which yields an additional basis for separately considering the air pollution potential in each area. Coastal areas which merge climatically when the distribution of continentality and average daily temperature range are considered (Figures 8 and 9) are well delineated climatically by the element of wind circulation. Although the typical surface wind flow patterns assist in understanding the climatic separateness of the various areas, a clearer picture of the air pollution potential is provided by consideration of the spatial distribution of wind-speed frequency. A convenient way to do this is to separate the wind-speed occurrences according to some arbitrary value. Official tabulations of wind speed can be partitioned to show frequency of speeds 0 to 3 mph and 4 mph or over. Thus wind conditions which hinder or assist in the natural ventilation of an area can be examined.



OREGON
NEVADA
MEXICO
ARIZ.
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°
SAN FRANCISCO
SACRAMENTO
SAN JOAQUIN
CONTRA COSTA
STANISLAUS
MERCED
MONTEREY
SANTA BARBARA
MOHAVE
YUMA
IMPERIAL
CLARK
MINERAL
ESMERALDA
BUTTE
SUTTER

APRIL

PREDOMINANT MEAN CIRCULATION of the SURFACE WINDS

NOTES:
1. ARROWS FLY WITH THE WIND 5⟩——
2. ● = WIND DATA BASED ON COMPLETE 24-HOUR RECORDS
3. ○ = WIND DATA BASED ON INCOMPLETE HOURLY RECORDS
4. AVERAGE WIND SPEEDS ARE FOR PREDOMINANT DIRECTION ONLY
5. SHADING REPRESENTS MOUNTAINOUS AND INTERMEDIATE AREAS
6. PLOTTED NUMBERS ARE PERCENT FREQUENCY OF INDICATED DIRECTION

SCALE IN MILES
0 10 20 40 60 80

FIG. 11

C-2238-F-11

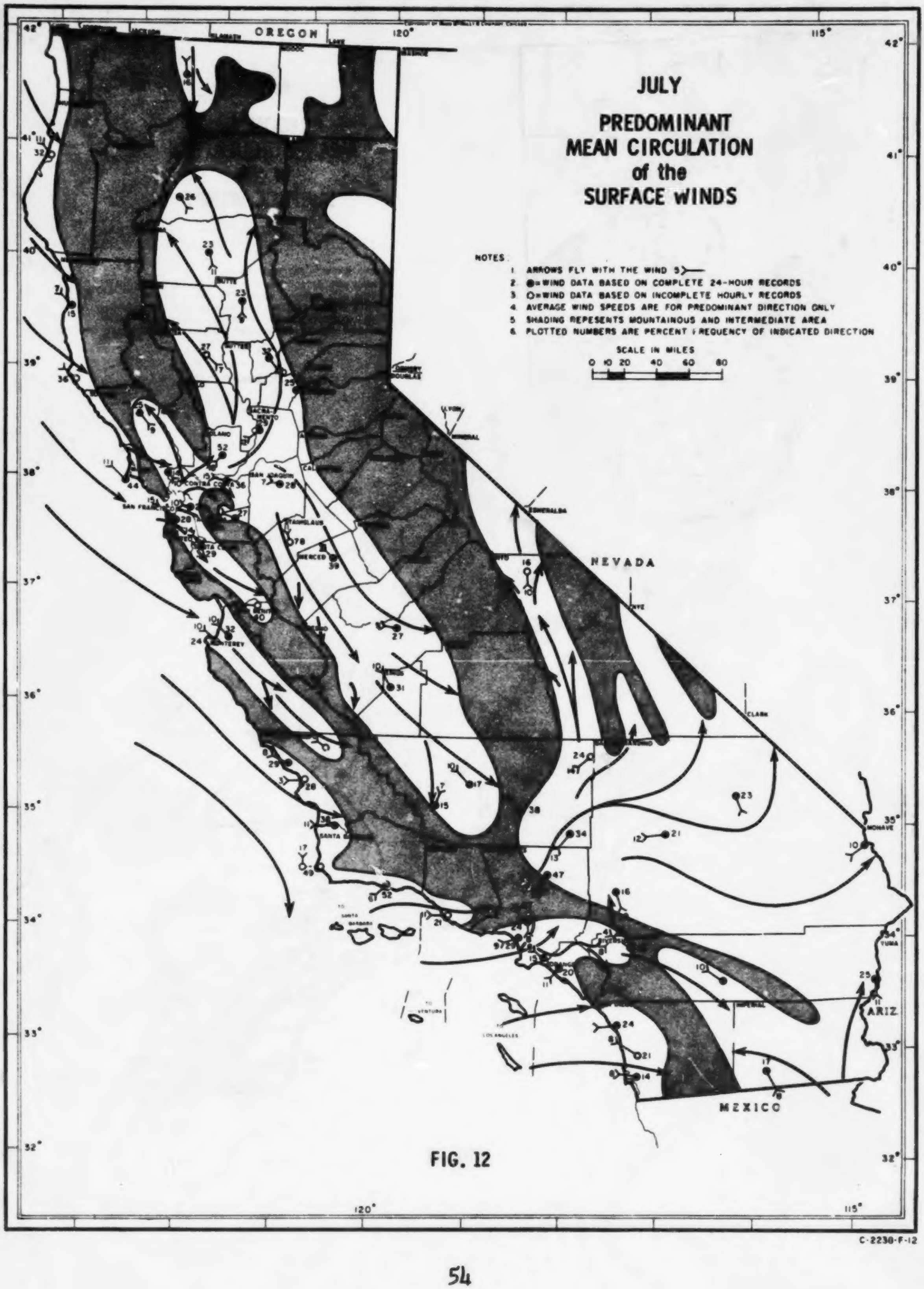
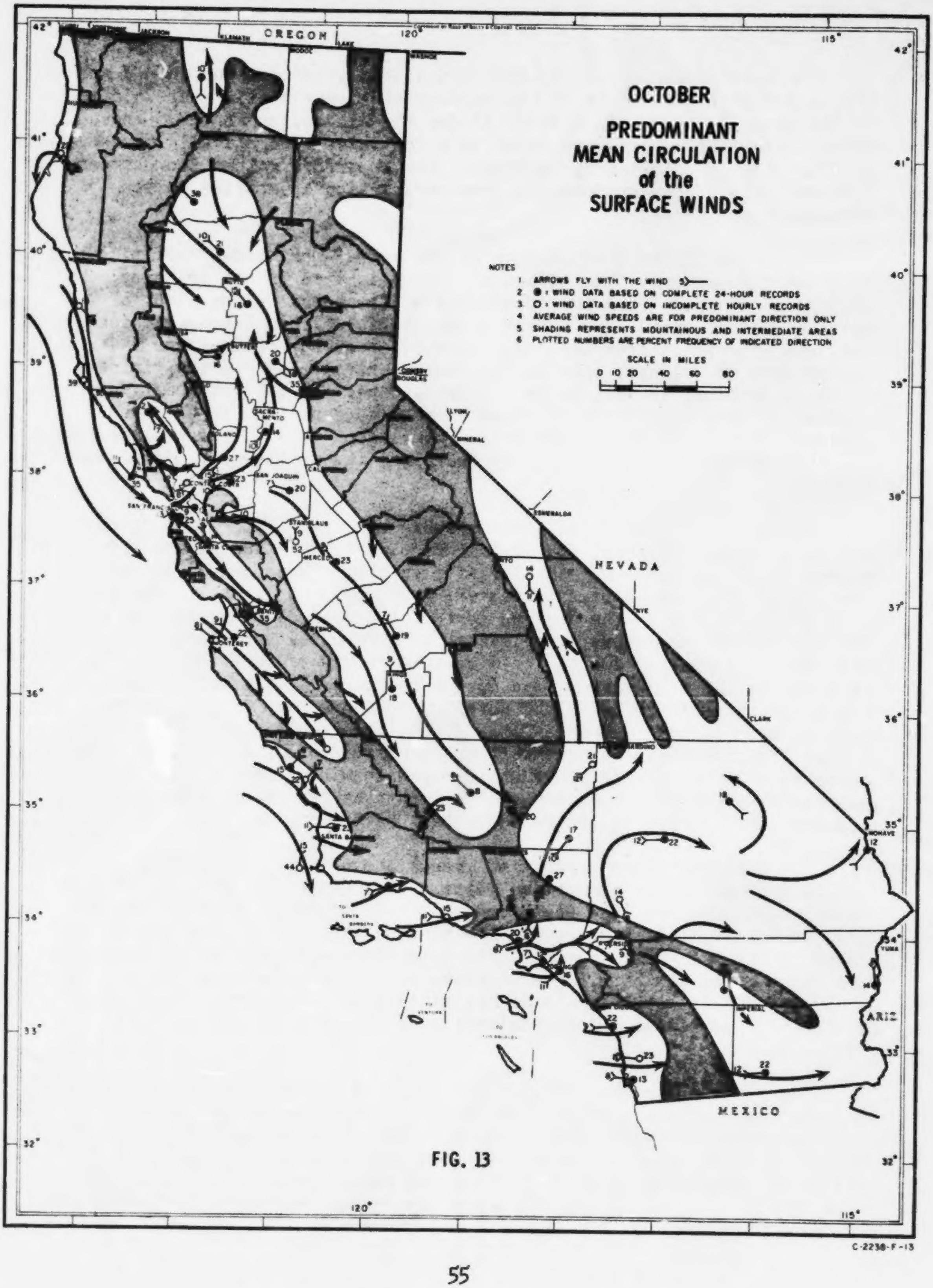

JULY
PREDOMINANT
MEAN CIRCULATION
of the
SURFACE WINDS
NOTES:
1. ARROWS FLY WITH THE WIND 5>——
2. ● = WIND DATA BASED ON COMPLETE 24-HOUR RECORDS
3. ○ = WIND DATA BASED ON INCOMPLETE HOURLY RECORDS
4. AVERAGE WIND SPEEDS ARE FOR PREDOMINANT DIRECTION ONLY
5. SHADING REPESENTS MOUNTAINOUS AND INTERMEDIATE AREA
6. PLOTTED NUMBERS ARE PERCENT FREQUENCY OF INDICATED DIRECTION
SCALE IN MILES
0 10 20 40 60 80
OREGON
NEVADA
MEXICO
ARIZ.
SAN FRANCISCO
MONTEREY
120°
115°
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°

FIG. 12

C-2238-F-12



OCTOBER

PREDOMINANT
MEAN CIRCULATION
of the
SURFACE WINDS

NOTES
1 ARROWS FLY WITH THE WIND 5>——
2 ● = WIND DATA BASED ON COMPLETE 24-HOUR RECORDS
3 ○ = WIND DATA BASED ON INCOMPLETE HOURLY RECORDS
4 AVERAGE WIND SPEEDS ARE FOR PREDOMINANT DIRECTION ONLY
5 SHADING REPRESENTS MOUNTAINOUS AND INTERMEDIATE AREAS
6 PLOTTED NUMBERS ARE PERCENT FREQUENCY OF INDICATED DIRECTION

SCALE IN MILES
0 10 20 40 60 80
OREGON
NEVADA
MEXICO
ARIZ
JACKSON
KLAMATH
LAKE
MODOC
WASHOE
DOUGLAS
LYON
MINERAL
ESMERALDA
NYE
CLARK
MOHAVE
YUMA
IMPERIAL
SACRAMENTO
SAN JOAQUIN
STANISLAUS
MERCED
FRESNO
MONTEREY
SAN FRANCISCO
SUTTER
BUTTE
SANTA BARBARA
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°

FIG. 13

C-2238-F-13

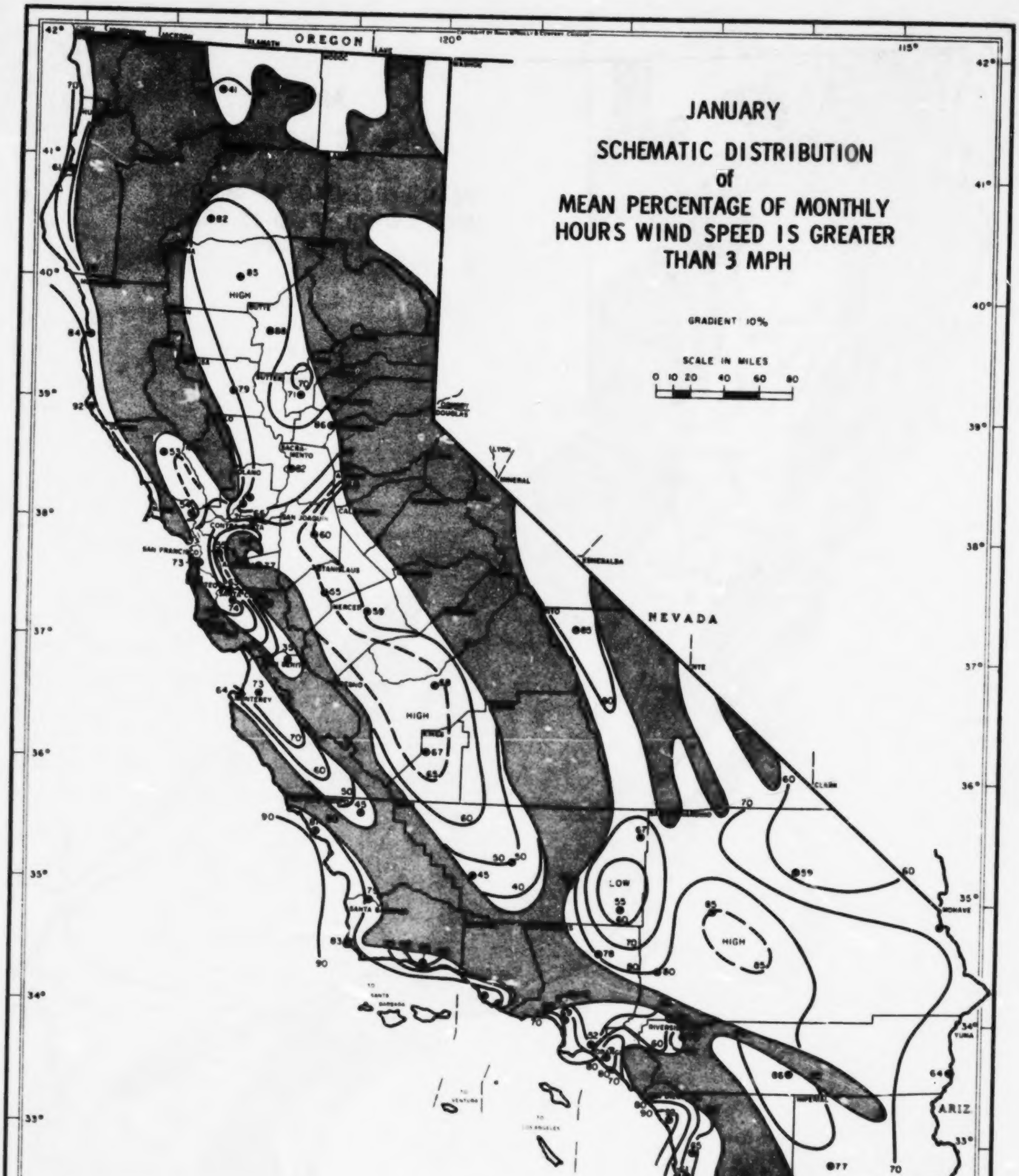
The mean percentage of monthly hours that winds greater than 3 mph (for all directions) occur at the various observing stations are plotted on the maps of Figures 14 through 17 for the mid-season months. The spatial distribution of wind speed is illustrated schematically by drawing lines of constant percentage. The knowledge gained from streamline analysis of the predominant wind circulation is applied in the wind-speed analysis.

In Figure 14 the distribution of the over-3-mph wind-speed frequency is shown for January. The effect of channelization in the principal valleys is apparent from the occurrence of frequency maxima along or near the valley axes. The effect of sheltering by local topographical features is evident from the occurrence of frequency minima near the closed ends of valleys; also on the south central coast in the vicinity of Santa Barbara, as well as in the western part of the Southeast Desert region. Minima also occur in areas where divergent flow is produced downwind from local channelization. Examples of this effect are seen in the east-central Sacramento Valley and along the northeastern San Joaquin Valley.

During April (Figure 15) when onshore and up-valley circulations are being re-established, the distribution of circulation maxima and minima is not exceptionally different from that of January. Minima associated with topographical sheltering effects retain their identity with the exception of the western part of the Southeast Desert where effects leading to greater persistence of stronger local winds are indicated. A minimum due to the divergent nature of the wind flow is retained in the northeastern San Joaquin Valley. The effect of local channelization appears with the advent of onshore flow in the Sonoma Valley north of San Francisco Bay. Channelized flow into the Coachella Valley from the basin in northwestern Riverside County introduces a new maximum. Figure 15 also shows an increase in wind movement over the Southeast Desert region as temperature contrast builds up between coast and interior (Figure 9) in the south part of the state.

The distribution of mean wind speeds above 3 mph during July (Figure 16) is typical of the summertime pattern of onshore sea breezes and local valley wind effects. The south coastal plain of Santa Barbara County and the Los Angeles Basin retain the minimum wind speed characteristics found in other seasonal months. The upper Sonoma Valley and northeastern San Joaquin and southern Butte Counties show only a tendency toward lower wind speeds. All other areas in the state show sufficiently high percentages to emphasize the persistence of a channelized wind pattern during summer.

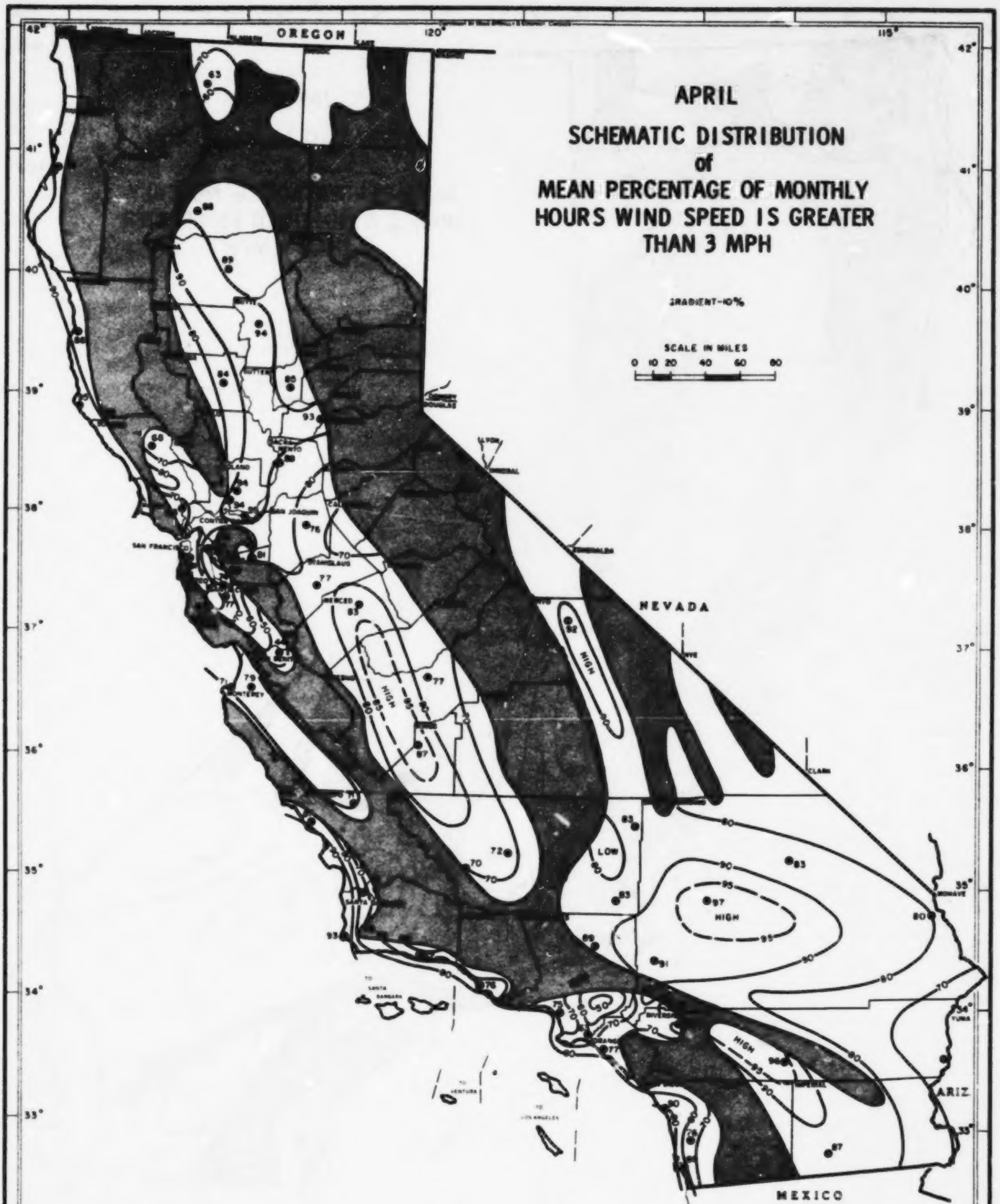
The month of October (Figure 17) reflects the relaxation in wind circulation over the southeastern Desert Plateau due to the seasonal cooling of the interior land surfaces. The effect is sufficiently marked that the area is characterized by minima as contrasted to the maxima in spring and summer. Circulation minima in southern Santa Barbara County and the Los Angeles basin are further emphasized. A seasonal


OREGON
NEVADA
MEXICO
ARIZ
GRADIENT 10%
SCALE IN MILES
0 10 20 40 60 80
HIGH
LOW
SAN FRANCISCO
SACRAMENTO
MONTEREY
SANTA BARBARA
MOHAVE
YUMA
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°

JANUARY
SCHEMATIC DISTRIBUTION
of
MEAN PERCENTAGE OF MONTHLY
HOURS WIND SPEED IS GREATER
THAN 3 MPH

FIG. 14

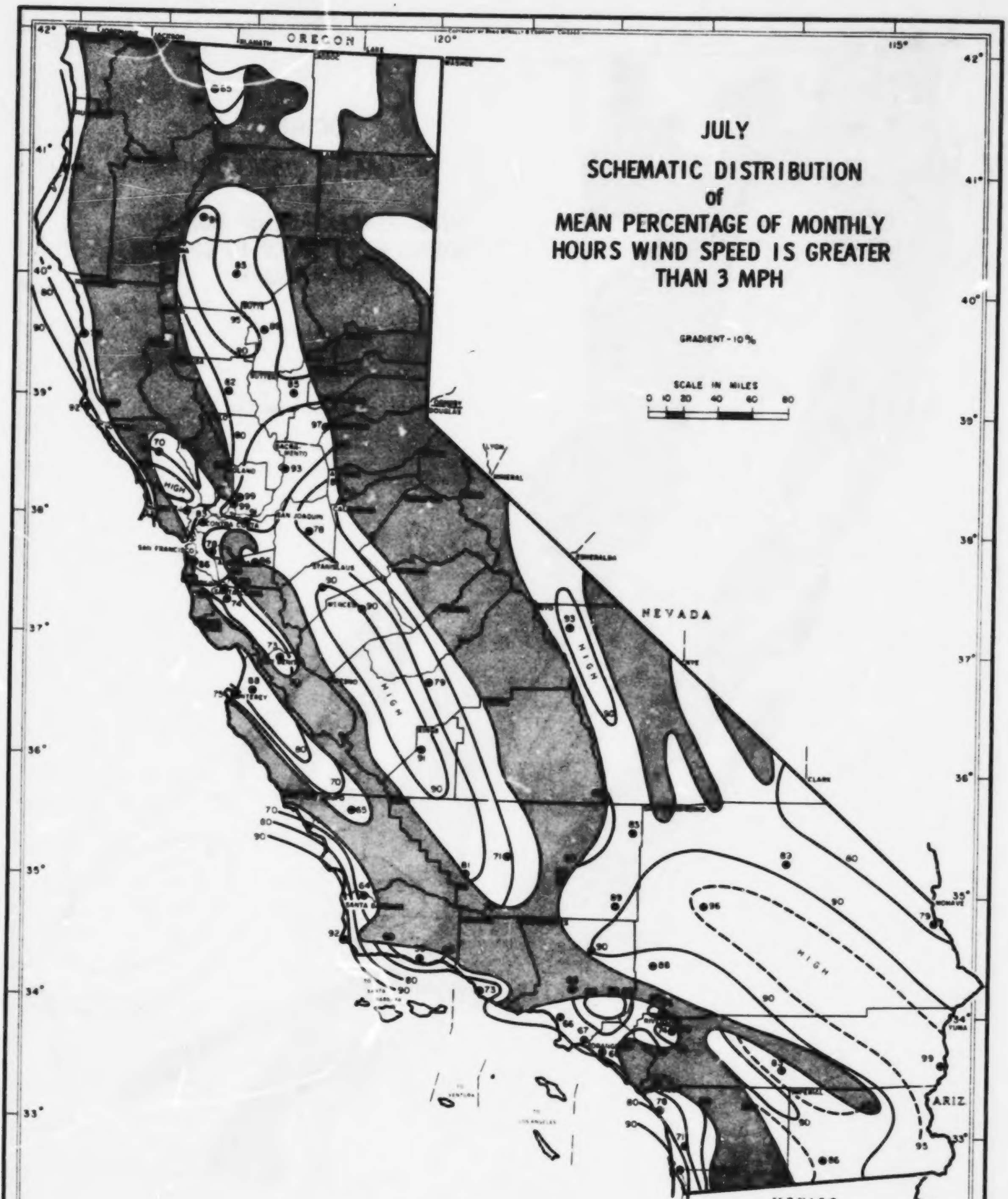
C-2238-F-14


OREGON
NEVADA
MEXICO
ARIZ.
SAN FRANCISCO
MONTEREY
HIGH
LOW
GRADIENT-10%
SCALE IN MILES
0 10 20 40 60 80
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°

APRIL
SCHEMATIC DISTRIBUTION
of
MEAN PERCENTAGE OF MONTHLY
HOURS WIND SPEED IS GREATER
THAN 3 MPH

FIG. 15

C-2238-F-15

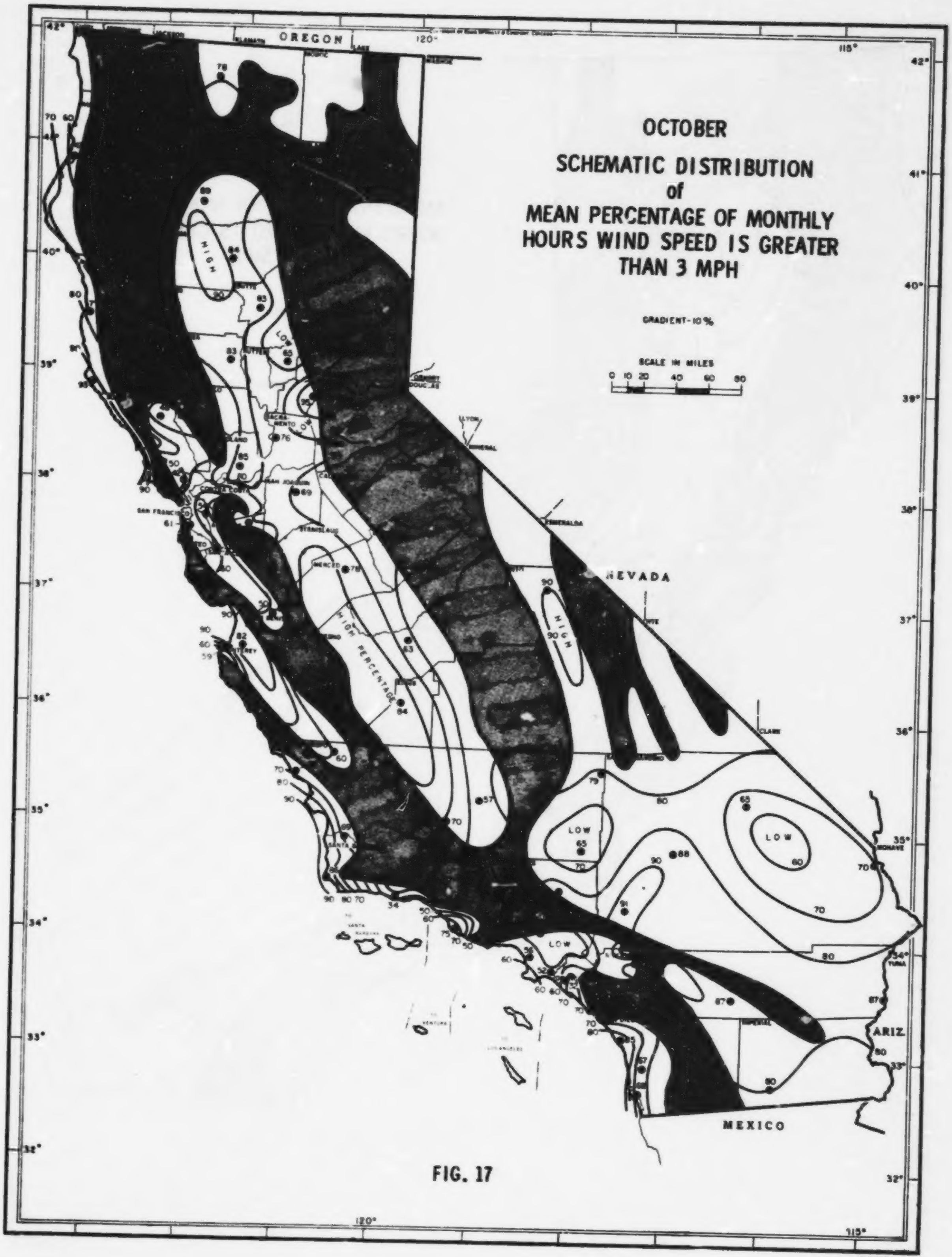


OREGON
NEVADA
MEXICO
ARIZ
HIGH
GRADIENT - 10%
SCALE IN MILES
0 10 20 40 60 80
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°
SAN FRANCISCO
SACRAMENTO
SAN JOAQUIN
STANISLAUS
MONTEREY
SANTA B
MOHAVE
YUMA
CLARK
ESMERALDA
DOUGLAS
LYON
MINERAL
NYE
90
80
70
95
93
99
97
85
83
79
73
71
96
88
86
92
65

JULY
SCHEMATIC DISTRIBUTION
of
MEAN PERCENTAGE OF MONTHLY
HOURS WIND SPEED IS GREATER
THAN 3 MPH

FIG. 16

C-2238-F-16



OCTOBER

SCHEMATIC DISTRIBUTION
of
MEAN PERCENTAGE OF MONTHLY
HOURS WIND SPEED IS GREATER
THAN 3 MPH

GRADIENT-10%
SCALE IN MILES
0 10 20 40 60 80
OREGON
NEVADA
MEXICO
ARIZ.
HIGH
LOW
HIGH PERCENTAGE
SAN FRANCISCO
MERCED
STANISLAUS
ESMERALDA
CLARK
MOHAVE
YUMA
IMPERIAL
120°
115°
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°

FIG. 17

C-2238-F-17

minimum is created in southern Butte and northern Yuba counties by the confluence of up- and down-valley wind flow as shown in the October wind circulation map of Figure 13. The sheltering influence of the mountains bounding the southern end of the San Joaquin Valley is responsible for the minimum shown in this area. Similar conditions characterize the upper Sonoma Valley, Santa Clara County, and parts of Alameda County.

As described in Section IV-B-1 characteristic wind movement also can be demonstrated with use of the geographical distribution of total mean miles of wind per 24 hours* as shown in Figure 18 for the month of October. Corrected data from run-of-the-wind anemometers exposed at evaporation stations in various parts of the state are used to supplement the data calculated from regular observation points. The distribution of data in Figure 18 shows that in the southeastern Desert Plateau the daily wind movement is fairly high in October. In Figure 17 the data distribution for the same area shows that the frequencies of wind speeds above 3 mph are diminished. This suggests that this area is characterized by rather high wind speeds during daylight hours. In all other areas with the possible exception of Santa Clara and western Alameda Counties, the data distributions in Figures 17 and 18 give compatible indications of wind movement.

The gross surface wind circulation in California as indicated in Figures 10 through 18 is characterized generally by a seasonal reversal of air flow between summer and winter. The transitional seasons appear to account for the highest incidence of unfavorable natural ventilation. The areas affected most are those where local topography and geographical location contribute to the conditions causing lowered natural ventilation.

In most coastal counties where the gradient of daily temperature range is strongest (see Figure 9), there exists in almost all months a daily reversal of wind direction. The nighttime flow is from the land to the sea while the daytime flow is from sea to land. In some areas, particularly in the Los Angeles Basin where wind movement is low, the ebb and flow of the wind contributes to the accumulation of pollution from several days of human activities.

The standard forms of most historical wind summaries do not permit the extraction of hourly wind direction summaries. Hence it has not been possible to demonstrate for the coastal regions of the state, the distribution of ebb and flow patterns of surface winds. In general, the coastal plains and valleys extending inland from the coast, but not connecting with the Central Valley, exhibit a daily reversal of wind flow. A channel such as the Carquinez Strait connecting the onshore wind flow with the interior valley usually does not experience a pronounced daily reversal of wind flow.

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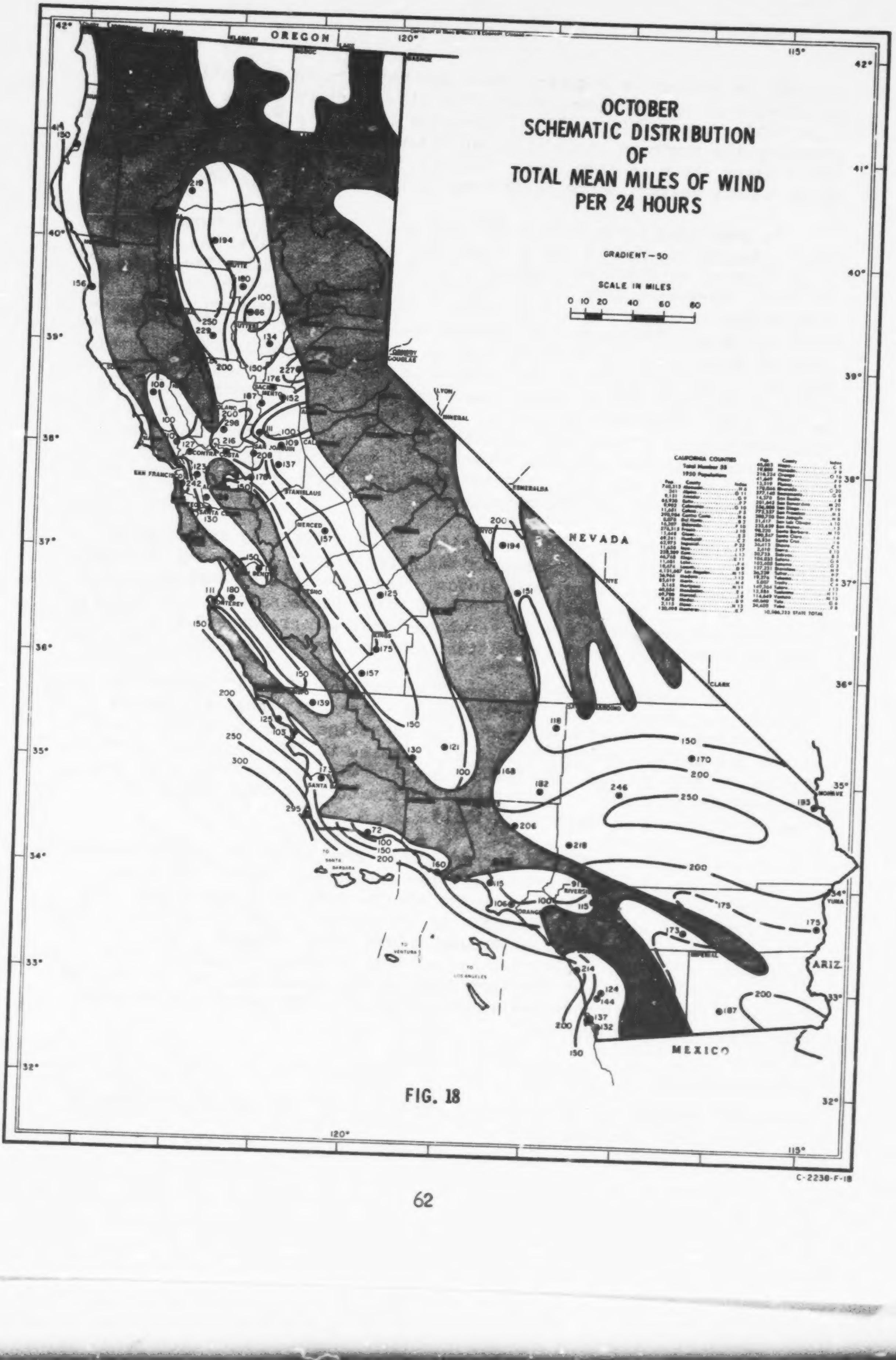
* Miles traveled by the wind in 24 hours at the average wind speed for the month at each station.



OCTOBER
SCHEMATIC DISTRIBUTION
OF
TOTAL MEAN MILES OF WIND
PER 24 HOURS

GRADIENT — 50
SCALE IN MILES
0 10 20 40 60 80
OREGON
NEVADA
MEXICO
ARIZ.
SAN FRANCISCO
CONTRA COSTA
SAN JOAQUIN
STANISLAUS
MERCED
MONTEREY
SANTA BARBARA
RIVERSIDE
ORANGE
IMPERIAL
CLARK
MOHAVE
YUMA
CALIFORNIA COUNTIES
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°
120°
115°
219
194
180
100
86
134
250
229
200
150
227
176
187
152
108
298
216
111
109
208
137
127
123
242
179
130
157
125
175
139
121
168
182
246
170
185
206
218
72
160
115
106
91
173
214
124
144
132
187
295
105
118
194
151
156

FIG. 18

C-2230-F-18

H. Geographical Distribution of the Subsidence Inversion

Before proceeding with a discussion of the mean distribution of the subsidence inversion over California, it is necessary to discuss the atmospheric processes responsible for the inversion and to define the relationship of this phenomenon with air pollution.

The general circulation of the atmosphere is reponsible for the existence of a belt of high pressure which encircles the globe in the Northern Hemisphere at an average latitude of about 35 degrees. The distribution of continental land masses causes discontinuities in the high pressure belt such that it is a persistent feature of the pressure pattern over the oceans. On the west coast of the North American continent the climate of the coastal areas is influenced by the semi-permanent eastern Pacific high pressure area. In addition to providing persistent winds along the coast during all except the winter months, the dynamics of the high pressure area circulation require that air flowing at the higher altitudes around the east side of the Pacific High must subside or descend. In the course of subsiding, the air is heated by compression as it reaches lower heights (higher atmospheric pressure).

The air in contact with the ocean surface along the coast is cooled and the temperature contrast between the cool surface air and the warm, subsiding air aloft produces a transitional layer through which the air temperature increases with height. This temperature transition layer is called a temperature inversion due to subsidence. The term temperature inversion is used since air temperature normally decreases with increasing height in the earth's atmosphere.

The subsidence inversion layer acts as a lid which limits the vertical motions originating in the marine air below. Vertically displaced air is cooled due to decompression when it reaches a higher altitude (lower atmospheric pressure). It will always be cooler than the air in the inversion layer. Upon reaching the inversion layer the air will sink back to its original level. This mechanism will prevail as long as a sufficient temperature contrast is maintained for a given inversion thickness.

The California coast is dominated by a semi-permanent subsidence inversion mostly during spring, summer, and fall months. The inversion surmounts the layer of cool marine air which enters the coast as a sea breeze. During daylight hours the marine air is heated by the land surface as it moves toward the interior. The change in its temperature occurs to a large extent within a short distance from the coast. During the summer and early fall months when the daily range of air temperature over the interior valleys is about 30 to 35°F it is doubtful that the subsidence inversion retains its identity during mid-day hours over interior areas due to heating of the surface air.

Along the coast the height and thickness of the inversion varies according to time of day as well as according to geographical position.

The daily variation in inversion base height is caused by the changes in solar heating of the land surface and the associated changes in the sea breeze. Inversion base heights are usually lowest in the late afternoon and highest in the early morning. The geographical variation along the coast of inversion base height, thickness, and stability is due to two aspects of the Pacific High. First, the Pacific High has a finite latitudinal extent. Second, the amount of subsidence varies with respect to the latitudinal distribution of the Pacific High circulation. Both the average circulation and the average latitude of the Pacific High are subject to seasonal variation. Relative to the California coast the lowest inversion base heights occur along the south central coast (between Oakland and Santa Maria) particularly during summer and fall months.

The subsidence inversion is an important contributor to the gross accumulation of air pollution not only because of its ability to suppress upward motion of air but also because the inversion base height fixes the volume of air in which pollutants may accumulate.

To delineate the distribution of the subsidence inversion over the California coastal areas use can be made of upper air data at Oakland, Santa Maria, and San Diego. Historical data are available for Long Beach, Auburn (Placer County), and Merced during months when the subsidence inversion is present. The latter two stations are in the Central Valley.

The day-to-day persistence of the subsidence inversion during summer and fall is a prominent feature principally over the coastal areas of California. First consideration was given to a mathematical method of manipulating inversion data for Oakland, Santa Maria, and San Diego to provide a graphical picture of the continuous distribution of inversion properties along the entire coast. A method first developed in the Applied Climatology Laboratories of the U.S. Navy Post-Graduate School in Monterey was used to accomplish the interpolation and extrapolation of pointwise data along the entire coast. The method and its physical justification are discussed in detail in Appendix A.

The calculated distributions of inversion properties are shown in Figures 19 through 22 for the months of May, July, September, and October 1950-51. The median (most frequently occurring) inversion parameters were used for each set of computations.

In Figure 19 representing conditions during the months of May 1950-51, the coastal distributions with respect to the distance in miles north or south of Oakland (measured along the coast) of the inversion base height (Z), inversion thickness (ΔZ), and inversion stability ($\Delta\theta/\Delta Z$)*

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* For this discussion it is sufficient to realize that strong inversion stability is represented by large values of $\Delta\theta/\Delta Z$.

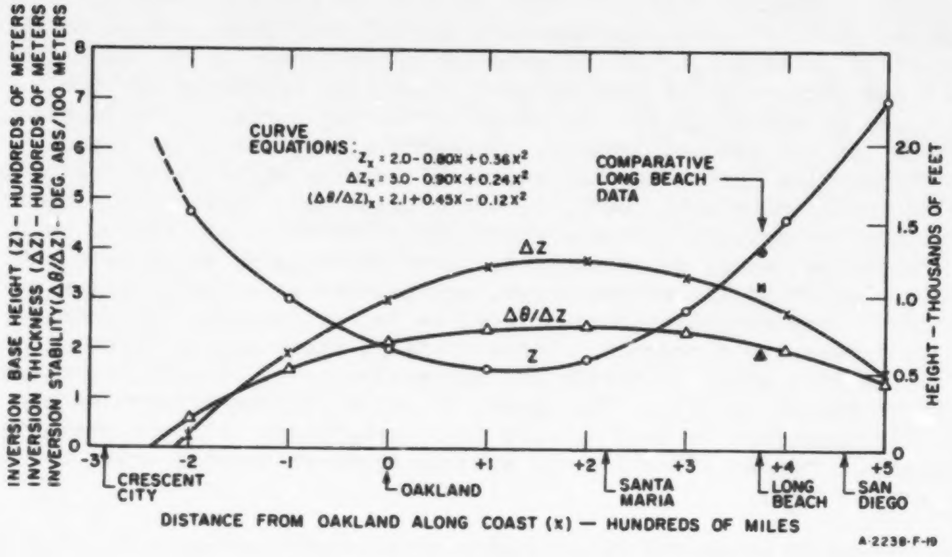

FIG. 19

CALCULATED COASTAL DISTRIBUTION OF MOST FREQUENTLY OCCURRING SUBSIDENCE INVERSION PARAMETERS—MAY 1950-51

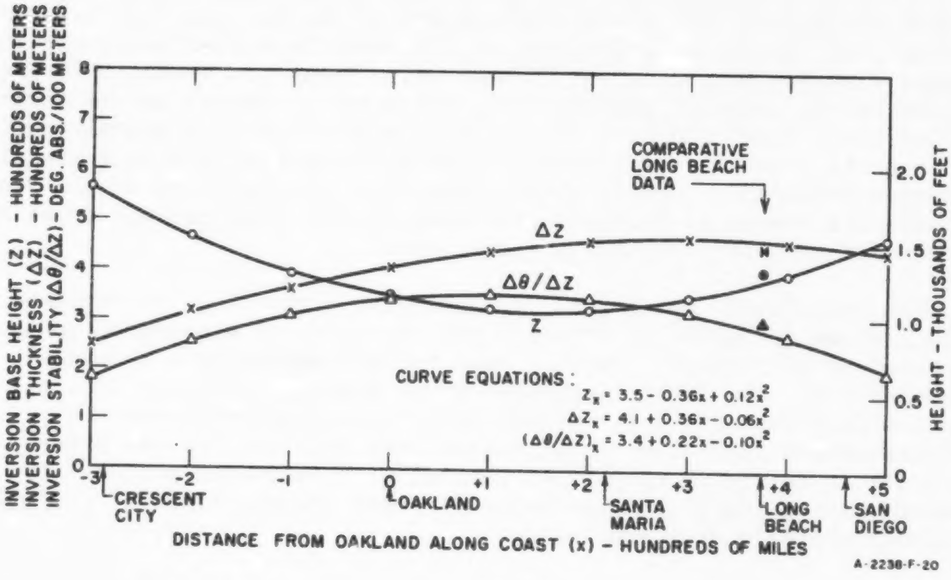

FIG. 20

CALCULATED COASTAL DISTRIBUTION OF MOST FREQUENTLY OCCURRING SUBSIDENCE INVERSION PARAMETERS—JULY 1950-51 are shown. Minimum inversion base heights and maximum inversion thickness and stability are situated in a coastal area about a hundred miles long and located 100 to 200 miles south of Oakland. As far as coastal areas are concerned the most adverse conditions affecting vertical dispersal of air pollution are indicated by the curves to be located between Santa Maria and Oakland. Somewhat higher inversion bases associated with less thick inversions of lower stability are indicated to the north and south. Decay of the subsidence inversion to minimum effectiveness appears to occur about 200 miles north of Oakland as far as the coastal areas are concerned. Long Beach data, which were not used in computing the curves shown, are plotted as a verification of the method of data manipulation, at least as far as Southern California coastal areas are concerned. Unfortunately, there are no upper air data available with which to verify the extrapolation of inversion properties to the north of Oakland. The manner in which various properties change with distance from Oakland appears to be consistent with the character of weather changes affecting the extreme northern coastal areas during the month of May.

Figure 20 shows the calculated coastal distributions of inversion properties for the months of July 1950-51. The curves show the entire coast to be under the influence of the subsidence inversion. Inversion base heights (Z) are higher along the central coast than in May. At the same time they are lower in the extreme north and extreme south coastal areas. The lowest subsidence inversion heights occur in May between 100 and 200 miles south of Oakland. These circumstances indicate that the latitude of the Pacific High center may be the same during each month or that during July the latitudinal extent of the Pacific High is greater than in May. In the southern part of the coast inversion thickness increases with distance south of Oakland while inversion stability decreases. This means that smaller temperature differences characterize the inversions over southern coastal areas. Thus, the inversion is less sharply defined. In the north coastal areas inversion stability decreases with decreasing inversion thickness. Due to higher inversion base heights and the fact that the sea breeze is strongly developed in July most coastal areas do not exhibit serious pollution accumulations.

The calculated distribution of inversion properties for September 1950-51 shown in Figure 21 indicate the beginning of a seasonal southward displacement of maximum inversion base heights and maximum thickness and stability. The latter inversion properties, in contrast to their relative July distribution, reflect an increased effectiveness for limiting upward diffusion of pollutants over southern coastal areas. The shift in inversion properties coupled with decreased surface wind movement causes increased occurrence of gross accumulations of pollution in topographically sheltered areas.

In October 1950-51 (Figure 22) a general lowering of inversion base heights occurs along the coast due to the merging of subsidence inversions with radiation inversions formed by nocturnal cooling of land surfaces. The greater incidence of these conditions in the central coastal areas

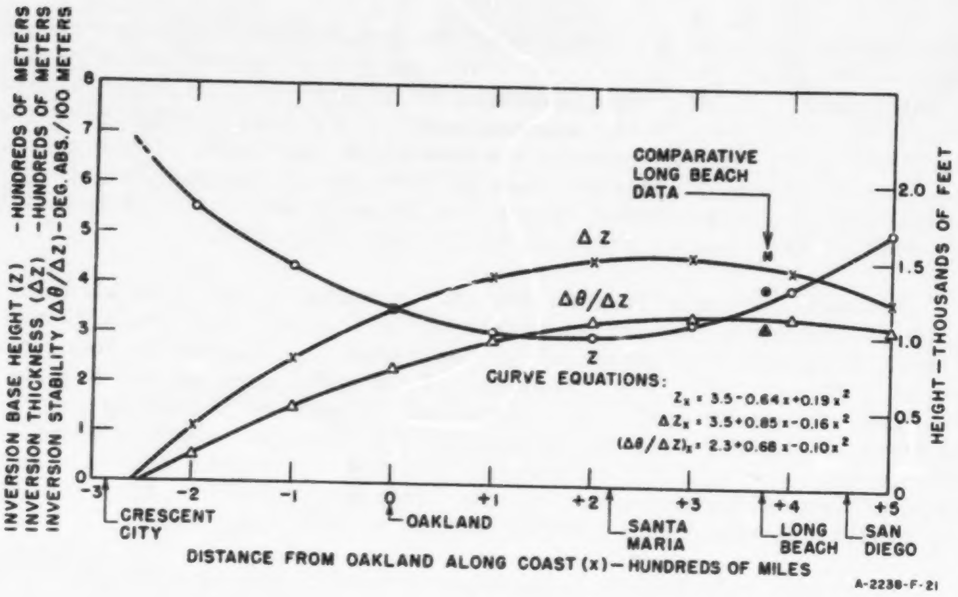

FIG. 21

CALCULATED COASTAL DISTRIBUTION OF MOST FREQUENTLY OCCURRING SUBSIDENCE INVERSION PARAMETERS — SEPTEMBER 1950-51

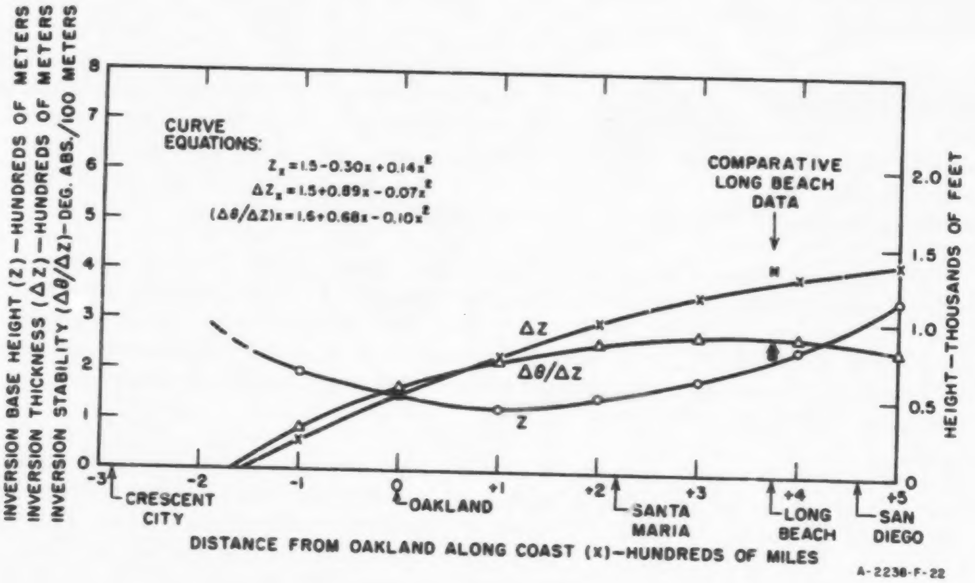

FIG. 22

CALCULATED COASTAL DISTRIBUTION OF MOST FREQUENTLY OCCURRING SUBSIDENCE INVERSION PARAMETERS — OCTOBER 1950-51 causes an apparent shift northward of the geographical area of minimum inversion base height. Continued displacement of the Pacific High causes the rapid decay of effective inversion conditions with distance north of Oakland. Due also to the encroachment of the Pacific High onto the California coast during October, surface winds over much of the coastal areas are considerably lighter than in September. The results of this combination of circumstances favors the gross accumulation of pollution over much of the coastal areas south of Cape Mendocino.

It should be borne in mind that the results on the coastal distribution of inversion properties displayed in Figures 19 through 22 reflect the most frequent occurrences of values based on atmospheric soundings made at 7 AM and 7 PM PST. Treatment of combined morning and evening data masks the daily variation. Seasonal changes reflected by this treatment of the data are in conformity with seasonal changes which characterize the synoptic climatology of the California coast. The method affords a demonstration of the large-scale distribution of inversion conditions based on a limited amount of upper air data.

Additional information concerning inversion characteristics can be had from the graphical correlation of inversion parameters. Using data for July 1950-51 from Oakland, Santa Maria, and San Diego as an example, inversion stability values ($\Delta\theta/\Delta Z$) have been plotted (Figures 23, 24, and 25, respectively), on triangular coordinates as a function of inversion base height, Z, (on the base axis) and the inversion thickness, ΔZ, (on the sloping axis). The array of valued points is arranged so that a crude isoline analysis is possible, even though there is considerable scatter of the points.

In Figure 23 Oakland inversion conditions during July 1950-51 show maximum stability for a range of inversion heights from 350 to 675 meters (1148 to 2214 ft) and of inversion thicknesses from 150 to 325 meters (492 to 1066 ft). A secondary stability maximum is suggested by the field of isolines in the same inversion height range for an inversion thickness range of 800 to 950 meters (2624 to 3116 ft).

At Santa Maria (Figure 24) during the same month (July) maximum inversion stability is associated with inversion base heights of from 200 to 600 meters (656 to 1968 ft) for a thickness range of 175 to 350 meters (574 to 1148 ft). A secondary maximum also is indicated in the same inversion base height range for a thickness range of from 300 to 950 meters (2296 to 3116 ft).

The San Diego data shown in Figure 25 indicate that maximum inversion stability is coincident with a range of inversion base heights from 425 to 650 meters (1394 to 2132 ft) and of inversion thickness from 200 to 300 meters (656 to 924 ft). A secondary maximum is suggested by the data for a range of base heights from 850 to 1050 meters (2788 to 3444 ft) for a thickness range from 50 to 200 meters (154 to 656 ft).

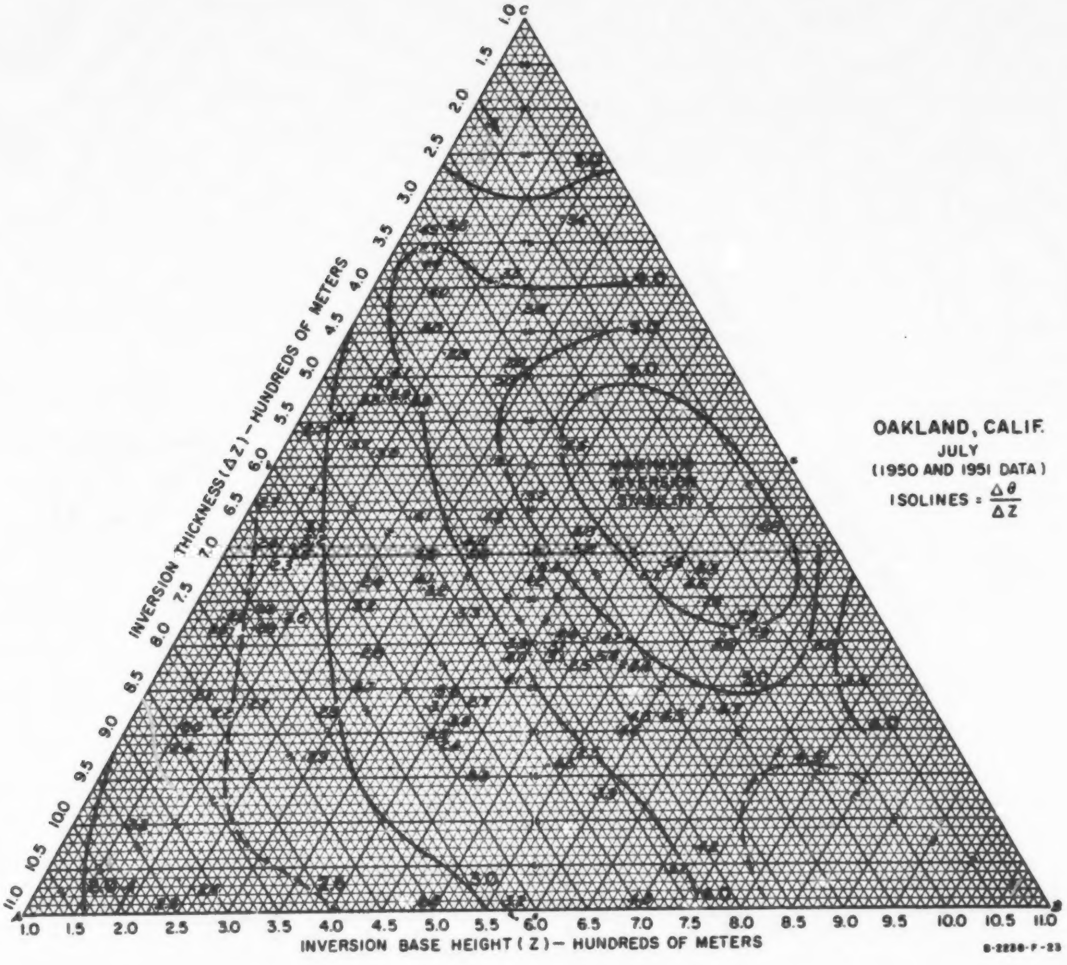

FIG. 23

VARIATION OF INVERSION STABILITY WITH RESPECT TO INVERSION BASE HEIGHT AND THICKNESSES OAKLAND, JULY 1950-51

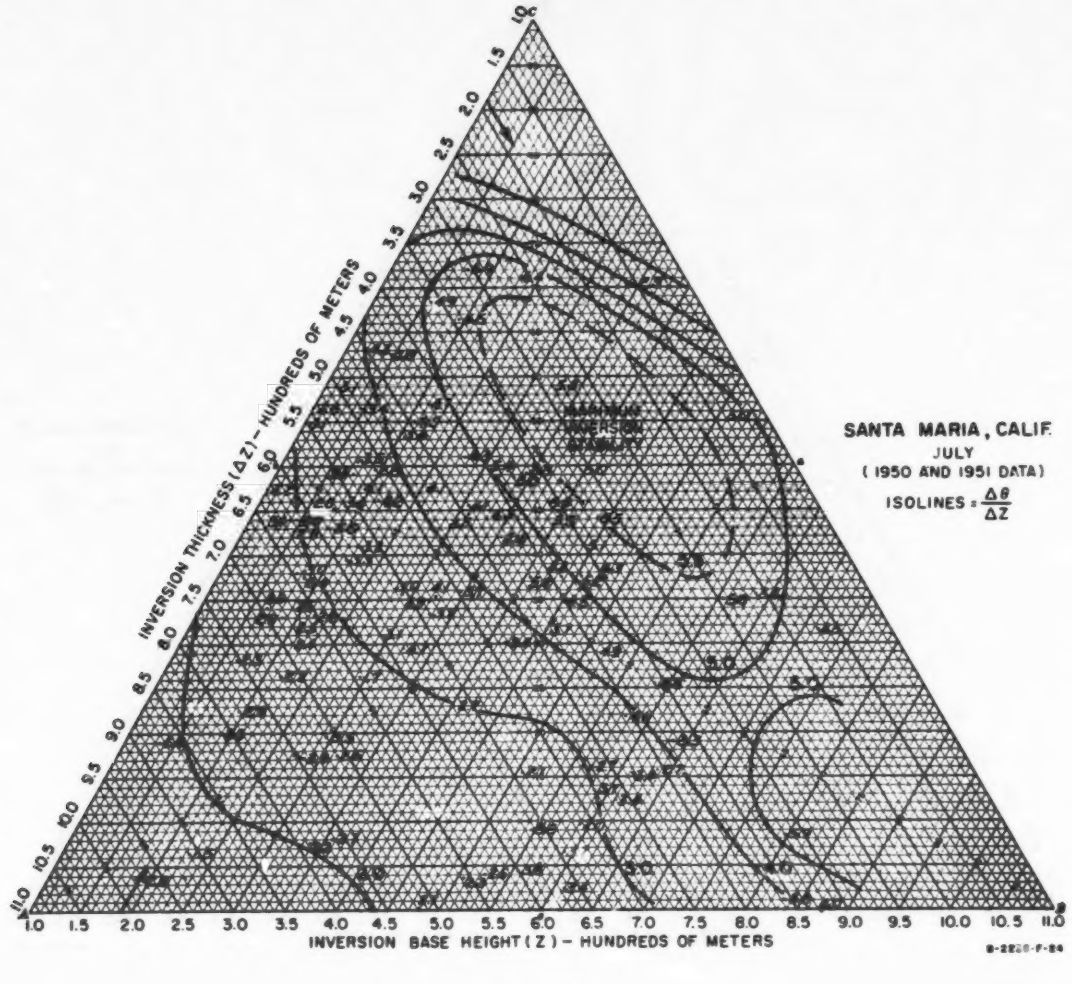

FIG. 24

VARIATION OF INVERSION STABILITY WITH RESPECT TO INVERSION BASE HEIGHT AND THICKNESSES
SANTA MARIA, JULY 1950-51

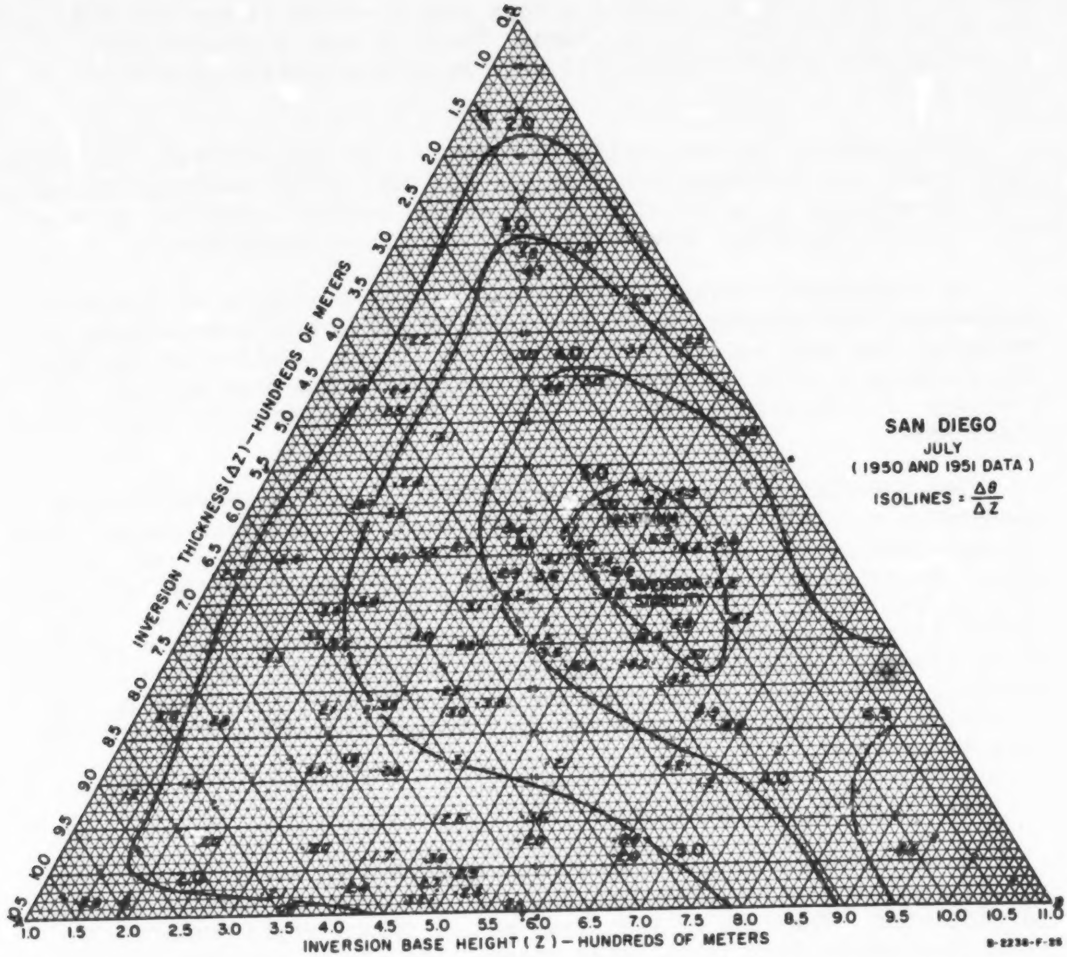

FIG. 25

VARIATION OF INVERSION STABILITY WITH RESPECT TO INVERSION BASE HEIGHT AND THICKNESSES
SAN DIEGO, JULY 1950-51

Comparison of the three charts indicates several interesting aspects. There is a decrease in maximum inversion stability at Santa Maria and San Diego with respect to Oakland. This is in keeping with the fact that the Pacific High occupies its northernmost position during July and that the subsidence mechanism is maximized in the central coastal area. This factor is also reflected by the shift of the secondary maxima of inversion intensity toward higher inversion base height values as one proceeds down the coast from Oakland to San Diego. There is also a greater range of inversion base heights associated with maximum stability inversions at Santa Maria.

The tendency for two stability maxima to be characteristic of inversion conditions indicates that the use of $\Delta\theta/\Delta Z$ as an inversion parameter must be preceded by an analysis of inversion data to establish an upper limit to the inversion base heights that are to be considered.

As a composite method of considering the co-variance of inversion parameters, the examples shown in Figure 23 through 25 are believed to represent the most readily interpretable form for considering the data for a single station. Comparison of results for the coastal upper air stations affords also a means of judging inversion characteristics along the coast.

The correlation on a coastwise basis of inversion properties and measurable or visible manifestations of gross air pollution accumulation has not been attempted. Because of the variety of topographical details which characterize the coastal areas, the relationship of similar inversion properties with pollution is variable over a broad range. It is doubtful that a general relationship exists which would provide continuity to an attempted calculation of coastwise distribution. The use of inversion properties in the creation of an empirical relationship with pollution, potential or otherwise, must be tested individually for each area of interest.

I. Radiation Inversions

At night whenever there is little surface wind movement and upper air layers are particularly dry, heat is lost from the earth's surface by radiation. The rate of heat loss may be fairly rapid particularly at points remote from large water areas. The air in contact with the ground is cooled more rapidly than air layers immediately above the surface. A temperature inversion is formed within an air layer which may vary in thickness from a few feet to several hundred. The thickness of the inversion depends on the rate and duration of the cooling due to radiational loss of heat.

In California over interior areas, radiation inversions of varying thickness and temperature difference form during the nighttime hours in almost every month of the year. These inversions are most prominent during the winter months whenever there is no storm activity. They tend to persist during the hours before noon due to the seasonally low solar angle.

In coastal areas, radiation inversions tend to form and merge with subsidence inversion conditions during the late fall months. During winter months radiation inversions form in sheltered areas but seldom occur or persist over a large area except on infrequent occasions.

Figure 26 shows histograms summarizing the frequency of early morning and evening radiation inversion thicknesses at Merced. These data were derived directly from tabulations made from WBAN 31-A adiabatic chart records. The data show the distribution of thickness frequencies for selected months of the year. The average daily range of surface air temperature for each month is shown on the 7 AM PST histogram. During May through September the daily range of temperature is large and the radiation inversions are eliminated shortly after sunrise due to heating of the earth's surface and the air in contact with it.

During the winter and late fall when the daily range of surface air temperature is less, radiation inversions persist often until noon. On some occasions they will persist for several days during which fogs often occur.* The range of temperature differences through the inversions is from 0.5°C to 7°C (0.9°F to 12.6°F), and the average temperature difference is about 1°C (1.8°F) in spring and early fall and 4°C (7.2°F) in late fall and winter.

These data are believed typical of interior areas west of the Sierra and north of the Transverse Ranges. The low visibility frequencies (shown in Table IX Section V-J) observed at stations in the San Joaquin Valley suggest that in the southern portion radiation inversions are not only more frequent but also more persistent during winter daylight hours. The Sacramento Valley appears to have more frequent inversion in the southern half than in the north during winter.**

Over the Great Basin, studies of radiation inversions at the China Lake Naval Ordnance Test Station (see sub-section J-7, below) indicate that radiation inversions persist until 8 or 9 AM in spring and summer and until noon during winter and late fall. Inversion thickness averages from about 950 ft in May and October to 1650 ft in January. The average inversion temperature difference ranges from 2°C (3.6°F) in March (windy month) to 7°C (12.6°F) in October. Conditions conducive to the accumulation of visible air pollution are reported to occur with reasonable regularity for a period of 2 to 3 hours after sunrise except during the months of March through June.

The radiation inversion is effective in localizing air pollution for a limited time after sunrise over interior areas. Occasions when the radiation inversion persists throughout the daylight hours are

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* Principally during a period of high atmospheric pressure following storm activity which has left the soil moist.

** Due to more frequent storm occurrences in the north part.

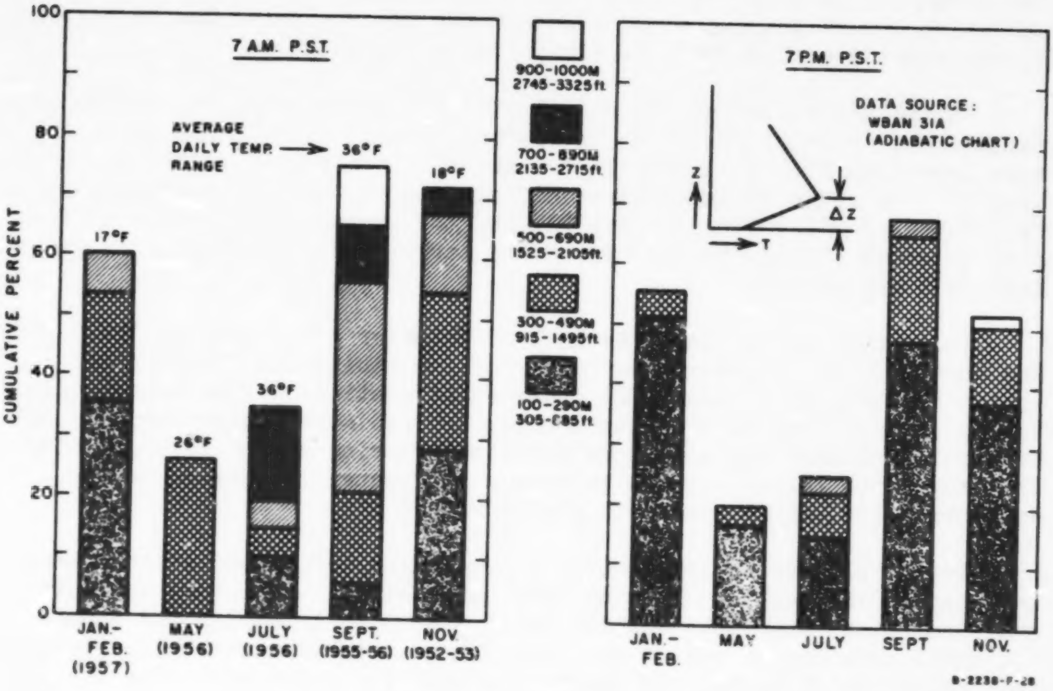


FIG. 26

FREQUENCY OF RADIATION INVERSION THICKNESSES—MERCED restricted to infrequent stagnation of high pressure systems during winter. In coastal areas, during fall and winter particularly, from the San Francisco Bay Area southward air pollution is held closer to the ground due to the combined influence of radiation and subsidence created inversions.

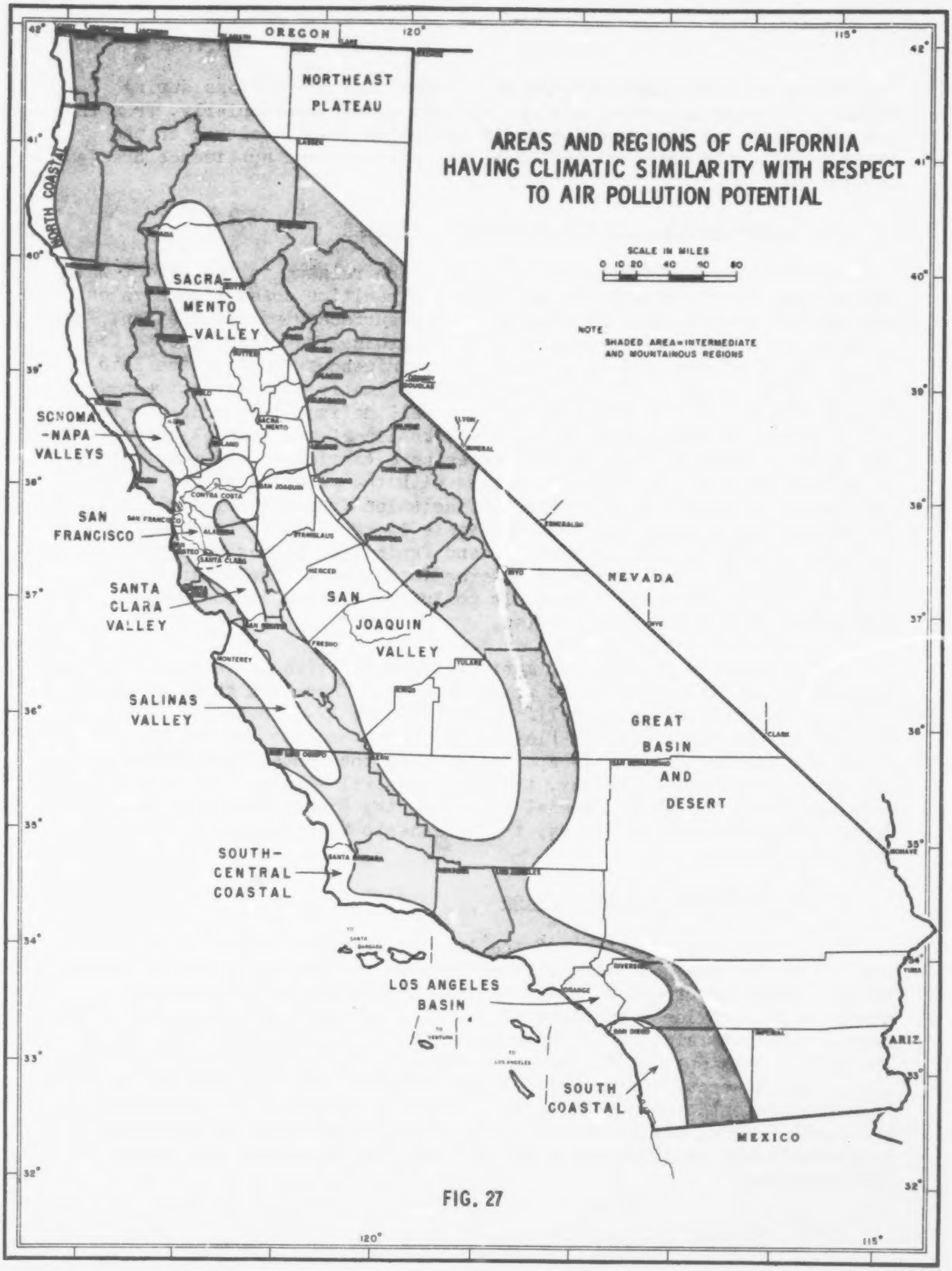
J. Summarization of Air Pollution Climates

Air pollution climates in California are related to the effect which its several mountain barriers and its long maritime coast line have on the general distribution of climates. The surface wind circulation, for example, is effectively channelized or otherwise restricted due to the distribution of the various mountainous prominences. During the late spring, summer, and early fall months the climatic contrast between coastal areas and the interior areas is well defined. This is due to the generally broad, multi-ranged distribution of the Coastal Ranges. The effectiveness of the Coastal Ranges as a barrier to the penetration of marine air into the interior varies with the relative height of the subsidence inversion base. Climatic isolation from the maritime influence of the extreme eastern parts of the state is provided by the southern Cascade, Sierra Nevada, Transverse, and Peninsular Ranges plus the climate modifying influences of intermediate areas. The definition of regional similarities as far as air pollution climate is concerned is summarized from this point of view.

In accordance with the climatic concept referred to in the foregoing, California is divided into ten prime regions. These are shown schematically on an outline map of California in Figure 27. These regions consist of the North Coastal Plains, the San Francisco Bay Region of which the Sonoma (Petaluma)-Napa Valleys and the Santa Clara Valley are sub-parts, the Salinas Valley, the South-Central Coastal Plains, the Los Angeles Basin, the South Coastal terraces, the Great Basin and Desert Region, the San Joaquin Valley, the Sacramento Valley, and finally, the Northeast Plateau.

1. North Coastal Plains

With the exception of the late fall months, areas in this region are favored generally with ample wind movement. In winter months between storm occurrences, brief periods marked by high atmospheric pressure can provide conditions of low wind movement and increased atmospheric stability similar to those occurring during the late fall months. The more persistent conditions unfavorable to the natural dispersal of air pollution occur during October and November when the Eastern Pacific High extends onto the coastal areas. The sea breeze which dominates the North Coastal plains during April through September and provides generally ample ventilation is subject only to infrequent and brief interruptions.



OREGON
NORTHEAST PLATEAU
NORTH COASTAL
SACRAMENTO VALLEY
SONOMA-NAPA VALLEYS
SAN FRANCISCO
SANTA CLARA VALLEY
SALINAS VALLEY
SAN JOAQUIN VALLEY
NEVADA
GREAT BASIN AND DESERT
SOUTH-CENTRAL COASTAL
LOS ANGELES BASIN
SOUTH COASTAL
MEXICO
ARIZ.
SCALE IN MILES
0 10 20 40 60 80
120°
115°
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°

AREAS AND REGIONS OF CALIFORNIA HAVING CLIMATIC SIMILARITY WITH RESPECT TO AIR POLLUTION POTENTIAL

NOTE
SHADED AREA = INTERMEDIATE AND MOUNTAINOUS REGIONS

FIG. 27

C-2238-F-26

2. San Francisco Bay Region

The Coastal Ranges are discontinuous and of lower average height in the San Francisco Bay Region than elsewhere along the coast. The sea breeze is channelized principally through the Carquinez Strait to the interior. The configuration of hill structures paralleling the maritime coast and San Francisco Bay provides some sheltering from the sea breeze to extremities of the Bay Area as well as to valleys extending roughly north (Napa and Petaluma Valleys) and south (Santa Clara Valley) of the Bay. The surface wind circulation is affected most by the local topography whenever the height of the subsidence inversion base is near the average height of the local hill structures. Evidence for this can be observed in the manner in which the coastal stratus is distributed during low inversion conditions.

Light and variable wind conditions which favor air pollution accumulation are likely to occur daily in the sheltered portions of the Bay Area. During a Weather Bureau study of wind conditions in the San Francisco Bay Area, C. L. Smalley (9) found that light wind conditions persisted over the entire area most frequently during the fall and winter months. Table VIII shows Smalley's findings with regard to percentage frequency of light-variable wind conditions in the San Francisco Bay Area during 1952 to 1955.

Table VIII

PERCENTAGE FREQUENCY OF LIGHT-VARIABLE WINDS IN THE SAN FRANCISCO BAY AREA - (1952 to 1955)[a]

	Time of Day (PST)				
Month	0400 (%)	1000 (%)	1600 (%)	2200 (%)	All Hours (%)
Jan	39	32	30	35	34
Feb	41	29	20	43	33
Mar	31	30	4	26	23
Apr	33	19	1	13	16
May	31	14	2	14	15
Jun	17	7	0	6	7
Jul	12	5	0	4	5
Aug	9	15	0	4	7
Sep	38	38	2	22	22
Oct	52	39	5	34	32
Nov	58	44	23	51	44
Dec	35	27	22	31	29
Annual	33	24	9	24	22

[a] Reference (9)

During these occurrences of light and variable winds the throughput of air between the coast and the interior is at a minimum and pollution accumulation is maximized.

According to Patton (10) the mean height of the inversion base over the San Francisco Bay Area is about the same (approximately 1700 ft) for all wind directions from south through west to northwest, whenever stratus clouds cover the area. During clear northwest and westerly wind conditions the inversion base height averages about 700 ft. When north to northeast winds prevail the inversion base is less than 200 ft. Based on the findings in sub-section H above, the most frequently occurring inversion base height during May is 650 ft, during July is 1200 ft, and during October is less than 350 ft, and the height of the inversion base is slightly less over the southern part of the San Francisco Bay Area and the Santa Clara Valley than over the northern part and the Napa and Petaluma Valleys.

3. Salinas Valley

The narrow Salinas Valley, whose axis is parallel to the coastline, lies in the coastal area of California characterized by the lowest subsidence inversion base heights as interpolated by calculation between the upper air stations of Oakland and Santa Maria.* The Sierra de Salinas and Santa Lucia Range provide a mountain barrier in excess of 3000 ft which in concert with low inversion heights prevent the direct inflow of marine air except through the valley opening onto Monterey Bay. Pronounced channelization of the surface wind is created. During daylight hours rapid modification of marine air occurs as it flows up this long (100 mi plus) valley and the subsidence inversion is correspondingly weakened as the surface air is heated. Light variable winds occur 29 to 55 percent of the time in the vicinity of Paso Robles, which, coupled with the characteristically low nighttime inversion conditions, afford some opportunity for the gross accumulation of air pollution in the southern part of the valley. The amount of pollution will depend on the effective depth of the marine air layer.

4. South-Central Coastal Plains

The lowland areas along the coast are isolated from the interior by mountain barriers of significant height. Several blind valleys penetrate these mountains. These topographical characteristics provide the physical conditions necessary for the regular occurrence of an off-shore, drainage wind flow at night and an on-shore sea breeze during the daylight hours (11). This daily wind pattern of direction reversal is most typical of the areas north of Point Arguello. The narrow coastal plain in the vicinity of Santa Barbara is backed by the Santa Inez Range. This topographical feature coupled with the more or less east-west orientation of the coastline provides considerable sheltering from the direct ventilation by the northwesterly ocean breezes. The Oxnard plain in Ventura County is better ventilated due to the channelized sea breeze flow up the Santa Clara River Valley which penetrates the Transverse Ranges for a considerable distance. Nighttime land breezes blow offshore across the Oxnard plain throughout the year yielding to the sea breeze in prominence only during July, August, and September (12). It is the characteristic daily reversal of wind direction which combines the South-Central Coastal Plains into a common air pollution climate.

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* See Figures 19 through 22, Section V-H and Appendix A for results and discussion of method, respectively.

The subsidence inversion is persistent over the region. The inversion base heights are characteristically lower (about 500 to 1000 ft) over the areas north of Point Arguello and the base height increases gently with distance over the southern extremity of the region (1000 to 1500 ft).

The persistent inversion conditions, the daily reversal of wind direction, and the topographical sheltering in some areas combine to create a potentially adverse climate as far as air pollution is concerned.

5. Los Angeles Basin

Surface wind conditions in the Los Angeles Basin are characterized by a daily reversal in direction. During daylight hours winds blow from the coast toward interior areas of the basin and in the reverse sense at night. Due to the large area of the basin the prevalence of one direction of flow over the other varies with the season of the year. During late spring, summer, and early fall wind flow toward the interior of the basin predominates for the majority of the 24 hours. The predominant wind flow during later fall, winter, and early spring is from interior areas toward the coast (13).

The strength and depth of the on-shore sea breeze varies daily and the penetration of fresh marine air can often be distinguished from marine air that has been over the interior areas for 24 hours or more by a measurable contrast in temperature and moisture content at the advancing face of the fresh marine air. Excepting days when fresh marine air penetrates deeply into the basin, the air which lies beneath the subsidence inversion usually is moved back and forth across the region. This is brought about because the large-scale atmospheric pressure pattern does not produce sufficient wind movement to carry air completely out of the basin. The accumulation of air pollution in the same air thus can be integrated sometimes for a period of several days.

The height of the inversion base with respect to mean sea level is lowest along the north coastal parts of the basin (1300 to 1800 ft)* and increases in height toward the south (1500 to 2000 ft)* and over the interior portion (2000 to 4000 ft). The increased inversion base height relative to sea level cannot always result in a greater depth of marine air being available over the interior for dilution of pollutants. Land areas appreciably above sea level may be nearer the inversion base than coastal areas for a given base height distribution. During the hottest days of the summer and early fall at interior basin locations, (San Bernardino-Riverside County) the inversion thickness is diminished appreciably. Because of the heating of marine air during the long travel distance from coast to interior, the temperature contrast between the surface air layer and the warm air above it becomes less marked and probably disappears entirely close to the slopes of the eastern Transverse Range.

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* Heights during summer months. During late fall months the inversion base height varies from less than 300 ft to about 1200 ft.

The inversion base height is subject also to daily oscillation. Along the coast lowest heights occur in the later afternoon and early evening; whereas inland points experience lowest heights during early morning hours. These daily variations in inversion height bring about corresponding changes in the severity of pollution in the marine layer of air (13).

During winter months in the absence of storm activity, radiation type inversions accompanied by the occurrence of fog may persist for several days along the coast and over the interior parts of the basin (San Bernardino-Riverside area). The thickness of the inversion layer and the air temperature contrast through it are effective in holding pollutants near ground level.

6. South Coastal Terraces

This region is composed of the western part of San Diego County and is characterized by terrace-like hill structures which extend from the narrow coastal lowland to the ridges of the Peninsular Range. Several prominent canyons penetrate the hill structures and provide for channelization of wind flow.

As in the Los Angeles Basin, the surface winds exhibit the same daily reversal of wind direction as well as the seasonal predominance of the on-shore sea breeze in summer and of the off-shore land breeze in winter (13). Light and variable winds occur during the daily reversals of wind direction. The transition period during the morning between cessation of off-shore flow and the onset of the on-shore flow is longer in the fall and winter season than in the spring and summer season. According to Table III in Section IV-B-1 low wind speeds persist over longer periods of time in winter and later fall months than during other months of the year.

The subsidence inversion is a persistent feature of the spring, summer, and fall months and occurs part of the time during the winter months (occurs 29% of the time in December, 24% of the time in January, and 26% of the time in February) (14). Along the coast the inversion base is lowest at the north end of San Diego County (most frequent heights during summer and early fall months are in the 1300 to 2000 ft range) and slopes upward toward the south end of the county. Because of the rise of the terrain inland from the coast, the inversion base is often nearer the interior land surface than over the coast. This is in spite of the increase in height of the inversion relative to sea level over the interior. The inversion thickness and temperature contrast are diminished over the areas back of the immediate coast by heating of the on-shore wind flow as it moves over the land. Thus, during the mid-day hours the inversion is less capable of restricting the vertical dispersion of pollutants.

Radiation inversions 500 to 1000 ft thick occur on an average of 26% of nights in December, 26% during January, and 22% during February. The sea breeze, however, develops during the day more than 50% of the time. This factor, in addition to daytime heating, tends to nullify the effectiveness of the radiation inversion as a condition for the persistence of gross air pollution during winter.

7. Great Basin and Desert Region

As discussed in Sub-section F of this Section, the climate of this region is the most continental in character of any in California and is visited far less frequently by storm activity than the Northeast Plateau Region. During the daylight hours of spring and summer months surface wind movement is of the order of 300 to 350 miles per day over the Antelope Valley and the Mojave Desert. In other areas, such as the Owens Valley and the Imperial Valley, channelization of wind flow assures ample ventilation. During fall and winter months, average daily wind movement is less but still averages from 150 to 250 miles per 24 hours. During nighttime hours in all months of the year surface winds are light and variable.

A subsidence inversion surmounts the region only during periods of high pressure over the entire Great Basin and the inversion base is situated 8000 to 10,000 ft above mean sea level or approximately 4000 to 8000 ft above the average flat terrain (15). Radiation inversions develop during the night in all months and persist until shortly after sunrise in summer and as late as noon during winter in the more sheltered areas. The thickness of the inversion averages 1250 ft (above the terrain) for all months at the Naval Ordnance Test Station and varies from an average of 1000 ft in May to 1650 ft in January. The average difference between the surface air temperature and the inversion top temperature is 4.7°C (8.5°F) for all months and varies from an average of 2.9°C (5.2°F) in July and August to an average of 7.0°C (12.6°F) in October.

From an air pollution point of view, gross accumulations in this region are limited to that which might occur during nighttime hours. On a few occasions limited penetrations of visible pollution from the San Bernardino-Riverside portion of the Los Angeles Basin through the Cajon and Beaumont gaps have been observed. Plant damage due to air pollution has been observed in areas adjacent to these gaps by the University of California Riverside Experiment Station.

8. San Joaquin Valley

Except for the winter months, channelized wind flow from an average northwesterly direction affects most of the central axis areas of the valley. During winter months channelized windflow from the southeast dominates the central axis areas but the up-valley flow of wind from the northwest is almost as frequent. In the eastern, western, and southern perimeter areas of the valley drainage winds occur at night and up-slope winds during the day. The drainage winds are most predominant during fall and winter months as are up-slope winds in the spring and summer. The greatest daily incidence of light-variable winds occurs in these same perimeter areas during the transitional periods between cessation of drainage and onset of up-slope flows and vice versa. Light-variable winds appear also to occur in extreme northeastern San Joaquin County and southeastern Sacramento County as a result of the divergent character of channelized wind flow emanating from the Carquinez Strait during all except winter months. Part of this channelized flow moves northeastward into the Sacramento Valley and part moves southeastward into the San Joaquin Valley. It is in these perimeter areas that gross accumulation of pollution have the best chance of occurring.

The Pacific High pressure area subsidence inversion is not a persistent feature of the upper air temperature distribution over the great Central Valley. Figure 28 shows for Merced (Castle AFB) the cumulative frequency of inversion base heights above the terrain during the months of May, July, September, and November. These results are based on a limited number of data but give some indication of the inversion characteristics. Inversion base heights 1000 ft or less above the terrain based on soundings taken at 7 AM and 7 PM occurred 18% of the time in May, 27% in July, 15% in September, and 20% in November. These low frequencies, plus the fact that the inversions are most often destroyed during midday in summer and early fall,* preclude the occurrence of several days' build-up of pollution with the possible exception of the late fall months.

Radiation inversions form at night in all months of the year except during winter storm activity. The frequency of radiation inversion thickness at Merced is shown as an example in Figure 26 for January-February, May, July, September, and November based on morning and evening soundings. Inversion thicknesses of less than 1500 ft occur 54% of the time in January-February, 26% in May, 14% in July, 21% in September, and 52% in November at 7 AM, and 55%, 19%, 22%, 65%, and 52%, respectively, at 7 PM. Note also in Figure 26 the average daily ranges of surface air temperature. The range in spring, summer, and early fall is sufficiently large to cause disappearance of radiation type inversions within a few

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* Some data for midday soundings showed that practically no inversions of significant thickness and temperature contrast occurred during the summer and only a very few in the fall.

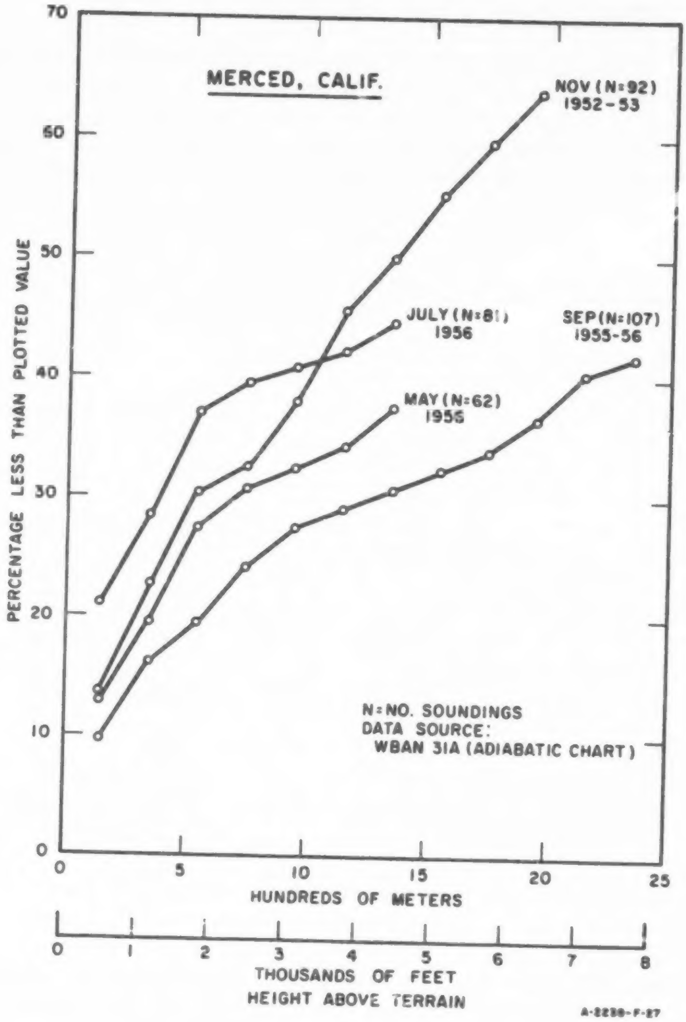

FIG. 28

CUMULATIVE FREQUENCIES OF SUBSIDENCE INVERSION BASE HEIGHTS — MERCED hours after sunrise since the inversion temperature difference seldom exceeds 5°F. During late fall and winter when the temperature difference seldom exceeds 8°F, the inversions persist until late morning. Local accumulations of pollution are possible during nighttime hours due to the incidence of radiation inversions. These conditions are subject to greater persistence during winter months.

Some idea of the distribution of atmospheric stability and surface wind stagnation can be obtained from a tabulation of hourly visibility observations of 6 miles or less for several stations along the Valley. Such a tabulation is shown in Table IX with the stations arranged in up-valley order (see Figure 1 for map of station locations).

Table IX

PERCENTAGE FREQUENCY OF VISIBILITY OBSERVATIONS $\leq$ 6 MILES AT SAN JOAQUIN VALLEY STATIONS FOR MID-SEASON MONTHS[a]

Station	Up-Valley Distance, (mi)	Years of Record	Months Jan	Apr	Jul	Oct	All
Stockton	14	5	28.4	7.0	1.8	20.4	14.4
Crows Landing	50	1	32.0	9.0	0.0	24.0	14.5
Merced	70	10	35.5	7.0	0.7	18.4	15.4
Fresno	125	5	39.3	2.3	0.0	5.0	11.8
Lemoore	155	2-1/2	41.6	7.1	0.0	6.9	13.9
Bakers-field	255	5	68.4	2.9	0.1	17.7	28.8

[a] Data sources: LCD, Supplement and WB Form 5108

The progressive increase during January in frequency of visibilities $\leq$ 6 mi very probably is a combined reflection of the increased incidence of radiation inversions and wind stagnation with distance up-valley. The distribution of frequencies during April and July substantiates the evidence of channelized up-valley wind flow generally indicated by surface wind data (Figures 11 and 12) as well as the non-persistent nature of inversion conditions. The double maximum distribution in October is very likely related to the coast-wise distribution of the subsidence inversion base height (see Figure 22) which is lowest in the coastal area opposite Fresno and Lemoore. The broad aspect of the Coast Range and the warm land surface combine to limit the development of atmospheric stability over the central part of the valley. The distribution of average 24-hr wind movement shown in Figure 18 above suggests also that the seasonal decline in wind speed is not uniform over the entire valley due to topographical factors and interaction of channelized and local wind flows.

9. Sacramento Valley

Channelization of up- and down-valley wind flow is also a characteristic of surface wind flow in the Sacramento Valley. During spring, summer, and early fall when winds enter the valley from the southwest after passing through the Carquinez Strait some sheltering occurs in Western Yolo County due to the range of mountains which extends along its western boundary into Solano County. Light variable winds thus are likely to predominate locally, especially in the fall months when local drainage winds interact with a weakening up-valley wind flow. The potential for gross pollution, thus, is increased.

As up-valley winds move deeper into the Sacramento Valley the characteristic direction becomes southsoutheast from the Sutter and Western Placer County area northward. This characteristic direction extends to the head of the valley during late spring, summer, and early fall. During October when the up-valley flow begins to weaken, the winds in the upper reaches of the valley become northwesterly. Opposition of these two wind flows provides light, variable wind conditions which lead to lowered natural ventilation in southern Butte County and northwestern Yuba County.

The divergent nature of marine air flow into the Sacramento and San Joaquin parts of the Central Valley causes less effective natural ventilation in the southern part of Sacramento County. This condition probably is best defined during early spring and late fall months as well as in winter months during intervals of several days between storm activity.

Atmospheric stability is difficult to assess in the Sacramento Valley because of a lack of upper air data. Sketchy upper air soundings were taken during 1946-47 at Auburn. The elevation of the observation point was 1650 ft and soundings in many instances were taken at 7 PM. Because of the limited number of soundings, knowledge of the height and persistence of the subsidence inversion is difficult to acquire from an analysis of the data. Figure 29 shows the cumulative frequency of subsidence inversion heights. Had a greater sample of data been available for analysis, displacements in the curves necessitated by gaps in the tabulations would not have occurred. Comparison of the data for November at Auburn with similar treatment of the data for Merced (Figure 28) would indicate that in the late fall the frequency of subsidence inversion occurrence in the south central Sacramento Valley is one-third to one-half that in the San Joaquin Valley. Base height of the inversions are somewhat higher also. The seasonal variation of inversion base heights suggested in Figure 29 for Auburn appear to be similar to the variation at Merced (Figure 28). The frequency of inversion base heights less than 3000 ft above the terrain at Auburn (elevation 1650 ft) is rather small.

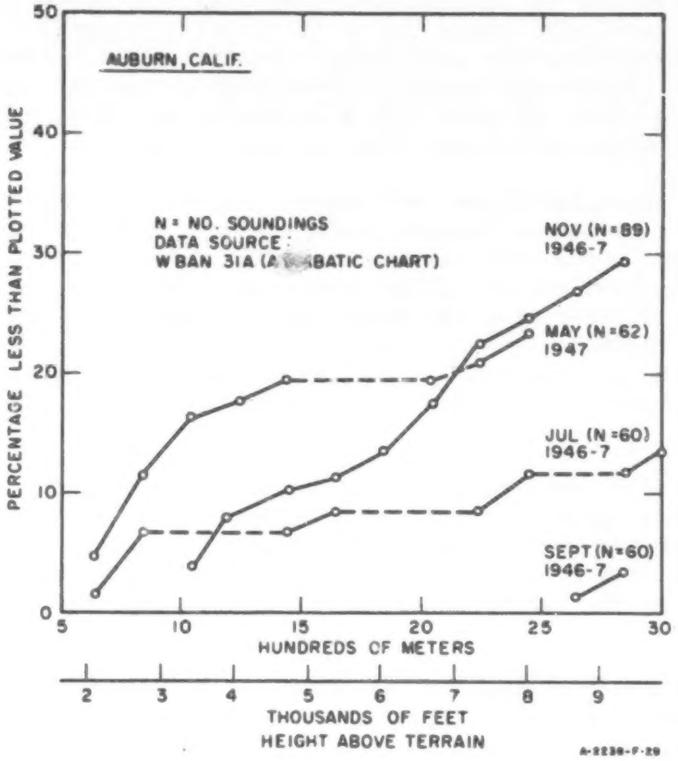

FIG. 29

CUMULATIVE FREQUENCIES OF SUBSIDENCE INVERSION BASE HEIGHTS — AUBURN

It is conceivable that more frequent occurrences would be observed at points nearer the axis of the Sacramento Valley.

Consideration of the geographic distribution of observed visibilities equal to or less than 6 mi provides a qualitative basis for judging the incidence of atmospheric stability of the order which might have a bearing on air pollution. A tabulation of this sort of data for stations distributed along the valley is shown in Table X.

Table X

PERCENTAGE FREQUENCY OF VISIBILITY OBSERVATIONS $\leq$ 6 MILES AT SACRAMENTO VALLEY STATIONS FOR MID-SEASON MONTHS[a]

Station	Up-Valley Distance, (mi)	Years of Record	Months				
			Jan	Apr	Jul	Oct	All
Sacramento	20	5	37.0	6.5	2.2	16.1	13.4
Marysville	50	1	24.0	10.5	0.0	3.7	9.6
Chico	105	3-1/2	26.2	8.7	0.2	10.0	10.1
Red Bluff	135	5	18.0	1.7	0.0	1.2	5.3

[a] Data Sources: LCD Supplement and WB Form 5108

The January distribution suggests that storm activity in the northern part of the state causes decreased incidence of stable atmospheric conditions in the upper Sacramento Valley. In April the data tend to peak between Marysville and Chico suggesting conformity with conclusions drawn from analysis of surface wind conditions (Section V-C). In October the Chico and Sacramento data appear to reflect similarity with the apparent distribution of light variable winds.

10. Northeast Plateau

Meteorological data from this area are restricted to sketchy fire-weather observations in summer and 6-hourly observations at Susanville Airport. Because the region is characterized by a considerable daily range of air temperatures (Figure 9) and is beyond the effects produced by the Pacific High, conditions leading to the potential occurrence of pollution are probably restricted to those occasions in fall and winter when a high pressure system stagnates over the region for several consecutive days.

VI Acknowledgments

The acquisition of data and information for this report represents a considerable part of the total effort, and the author is indebted to many persons for their assistance. In particular, recognition is made of the courtesy extended by Mr. R. W. Lundeen of the Dow Chemical Company for making available that company's wind records for their plant location near Pittsburg, California.

The helpful comments of Mr. George C. Holzworth, Weather Bureau Meteorologist, assigned by the U. S. Public Health Service to the California Department of Public Health, of Mr. Elmer Robinson of the San Francisco Bay Area Air Pollution Control District, and of Mr. R. F. Dale, State Climatologist, U. S. Weather Bureau, are gratefully acknowledged.

Appendix A

METHOD FOR CALCULATING THE COASTAL DISTRIBUTION OF SUBSIDENCE INVERSION PARAMETERS

I Introduction

To make full use of the inversion data derived from the upper air observations taken at Oakland, Santa Maria, and San Diego, some means was necessary whereby the coastwise distribution of inversion parameters could be calculated.

In 1954 Morris, et al. (16) developed an empirical method for interpolating and extrapolating the coastal distribution of inversion parameters by deriving a parabolic equation which expressed the continuous variation of a parameter as a function of the point-to-point distance between the reporting upper air stations. This method was deemed to have been based on a reasonable physical interpretation of the spatial variation of inversion properties along the California coast and was used, therefore, in preparation of the results displayed in Figures 19 through 22 (Section V-H) of this report.

II Discussion

The method of calculation to be described is related to the fact that the semi-permanent Pacific High off the coast of California possesses a circulation pattern which imposes a non-linear distribution of subsidence inversion conditions along the coast. It is assumed that this non-linear distribution is best described by a parabolic function of distance along the coast. This is because the curvature of the air flow about the high pressure area provides air flow toward the coast in the northern part of California, parallel to the coast in the central part, and away from the coast in the southern part. The subsidence mechanism is maximized in the central coastal area relative to the location of the most direct north to south air flow.

The strength of the circulation around the Pacific High and its position are subject to daily as well as seasonal variation. To examine the seasonal variation in subsidence inversion parameters, the inversion data for Oakland, Santa Maria, and San Diego during May, July, September, and October of 1950 and 1951 were used. Tabulations of inversion base height (Z), thickness (ΔZ), and stability ($\Delta\theta/\Delta Z$) were made with respect to small class intervals of values for each of these parameters. From these tabulations the most frequently occurring values of each parameter were selected for each month. Although this approach tended to mask daily variations in inversion conditions, it is believed that the resulting data give the most characteristic values for each month.

III Method

The general formula chosen for calculation of the coastal distribution of inversion parameters is a second order parabolic equation of the form:

$$I = I_0 + AX + BX^2 \qquad /1/$$

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where I is the value of any of the inversion parameters ($Z, \Delta Z$, or $\Delta\theta/\Delta Z$) at the distance X in hundreds of statute miles from Oakland. The convention that distance south of Oakland is positive distance and that north of Oakland is negative distance was adopted. Distance is measured along lines connecting the three upper air stations, and distance north of Oakland is along one extension of the line connecting Oakland and Santa Maria. I_o represents the inversion parameter value at Oakland, which was selected as the base station. A and B are coefficients expressed in terms of inversion parameter values at Oakland (I_o), Santa Maria (I_M), and San Diego (I_D).

The distance from Oakland to Santa Maria is 220 mi and from Oakland to San Diego via Santa Maria is 460 mi. (The extension of the Oakland-Santa Maria line intersects the California-Oregon border at the coast 300 mi from Oakland.)

The general equation can be set up for Santa Maria and San Diego in terms of the above distances which will allow the determination of the constants A and B as follows:

$$I_M = I_o + 2.2A + 4.84B \qquad /2/$$

$$I_D = I_o + 4.6A + 21.16B \qquad /3/$$

By difference after regrouping of terms

$$\begin{array}{l} (I_M - I_o) - 4.84B = 2.2A \\ (I_D - I_o) - 21.16B = 4.6A \\ \hline \end{array}$$

$$(I_M - I_o) - (I_D - I_o) + 16.32B = -2.4A \qquad /4/$$

Gathering terms and solving for B using Equations /2/ and /3/

$$0.455 (I_M - I_o) - 2.2B = 0.217(I_D - I_o) - 4.6B$$

$$-\left[0.19 (I_M - I_o) - 0.09(I_D - I_o)\right] = B \qquad /5/$$

Substituting Equation /5/ into Equation /4/ and solving for A gives,

$$0.88 (I_M - I_o) - 0.2 (I_D - I_o) = A \qquad /6/$$

Equations /5/ and /6/ substituted in /1/ give the working equation:

$$I = I_o + \left[0.88(I_M - I_o) - 0.2(I_D - I_o)\right] X - \left[0.19(I_M - I_o) - 0.09(I_D - I_o)\right] X^2 \qquad /7/$$

The coastwise distribution of an inversion parameter calculated with Equation /7/ is influenced not only by the distance from Oakland but also by the values at each point of measurement. For a particular set of data, positive or negative parabolic curves having a curvature relative to the point-wise data will result (Figures 19 through 22).

Appendix B

TABULATIONS OF WIND DATA

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Table B-I

PREDOMINANT WINDS AND WIND MOVEMENT DATA FOR CALIFORNIA STATIONS

Station, County	Period of Record	Month	Primary			Secondary			Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
			Frequency (%)	Direction	Mean[a] Speed (mph)	Frequency (%)	Direction	Mean[b] Speed (mph)		
1. Arcata,[c]	7/43-	Jan	24.4	SE	7.4	14.0	E	4.0	132	38.7
Humbolt	3/45	Apr	27.8	NW	7.8	15.6	SE	8.5	182	11.0
40°58'N		Jul	31.5	NW	11.3	17.3	WNW	6.0	175	20.4
124°6'W		Oct	21.9	SE	5.4	15.4	NW	6.6	120	43.1
2. Auburn,[d]	1/34-	Jan	24.0	E	-[e]	14.0	SE	-[e]	(252)[e]	13.6
Placer	12/38	Apr	21.0	E	-	13.0	SE	-	(230)	6.7
	less	Jul	25.0	E	-	18.0	SW	-	(235)	2.8
	6/11/34	Oct	35.0	E	-	10.0	SW	-	(227)	5.0
3. Bakersfield,[d]	9/52-	Jan	7.0	ENE	5.9	6.3	NW	8.9	73	50.1
Kern	9/57	Apr	15.1	NW	10.6	11.5	NNW	11.0	159	28.2
		Jul	16.5	NW	10.4	16.4	WNW	10.5	155	31.0
		Oct	7.8	NW	8.4	7.3	ENE	5.7	121	42.9
4. Bishop,[c]	1/48-	Jan	18.3	NW	7.4	15.9	N	11.4	(148)[e]	(14.9)[f]
Inyo	1/57	Apr	15.7	N	11.1	12.8	S	11.4	(235)	(8.0)
		Jul	15.9	S	10.3	11.0	NW	7.4	(175)	(6.9)
		Oct	14.4	S	11.1	12.6	N	10.9	(194)	(10.3)
5. Blythe,[d]	8/24-	Jan	15.1	NNW	11.1	10.2	N	7.4	158	36.1
Riverside	5/44	Apr	15.5	SW	11.5	13.5	S	8.2	187	33.7
		Jul	25.3	S	11.3	11.1	SW	10.4	225	1.1
		Oct	13.6	N	7.7	11.6	S	7.9	175	13.2
6. Burbank,[d]	5/50-	Jan	9.+	NNW	6.5	9.+	S	5.1	101	55.0
Los	4/55	Apr	17.0	S	7.0	6.0	NNW	10.9	139	38.0
Angeles		Jul	24.0	S	7.9	19.0	SE	6.0	132	35.0
		Oct	16.0	S	6.4	12.0	SE	5.2	94	54.0
7. Cambria,[d]	6/43-	Jan	30.1	N	5.6	16.7	NNE	5.3	156	12.9
San Luis	10/44	Apr	41.6	NW	11.7	18.8	NE	5.2	199	13.2
Obispo		Jul	29.4	NW	7.6	20.3	W	5.3	142	28.7
35°34'N		Oct	15.3	NE	3.7	13.4	NW	8.2	125	35.4
121°4'W										
8. Camp	8/42-	Jan	17.9	E	6.9	12.9	W	7.5	(149)[e]	(34.5)[f]
Kearny,[c]	3/45	Apr	21.7	W	8.3	14.5	NW	7.6	(168)	(23.9)
San Diego		Jul	20.9	NW	8.2	19.4	W	7.1	(166)	(28.5)
32°52'N		Oct	22.9	W	7.9	19.0	NW	3.7	(144)	(32.6)
117°7'W										

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Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary Frequency (%)	Primary Direction	Primary Mean[a] Speed (mph)	Secondary Frequency (%)	Secondary Direction	Secondary Mean[b] Speed (mph)	Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
9.Chico,[d] Butte	5/42-12/45	Jan	17.6	NW	9.0	17.2	SE	12.9	209	11.8
		Apr	17.8	NW	14.7	15.8	SSE	12.7	254	6.1
		Jul	22.5	S	8.8	21.4	SSE	9.4	182	12.0
		Oct	16.0	NW	9.3	12.7	SE	12.0	180	17.1
10.Crows Landing,[c] Stanislaus	1/44-2/45	Jan	21.0	S	7.8	27.5?	N	10.2	-[f]	(35.0)[f]
		Apr	33.3	N	15.6	12.7	NW	11.1	-	(23.0)
		Jul	78.5	N	10.8	8.6	NE	7.4	-	(10.0)
		Oct	51.6	N	8.5	11.9	NW	11.5	-	(31.0)
11.Dagget,[d] San Bernardino	5/51-12/54	Jan	22.0	W	11.5	20.4	WNW	11.5	217	14.9
		Apr	27.0	WNW	14.8	25.3	W	14.5	343	3.2
		Jul	21.1	W	12.4	24.1	WNW	12.9	288	3.7
		Oct	28.1	WNW	12.1	22.0	W	12.0	246	11.7
12.El Centro NAS,[d] Imperial	2/45-12/52	Jan	16.5	W	10.4	10.7	WNW	11.2	195	22.6
		Apr	29.0	W	14.5	9.7	WNW	8.8	247	13.4
		Jul	27.0	SE	8.2	9.3	SSE	8.0	198	13.5
		Oct	19.0	W	12.0	10.1	WNW	8.9	187	19.6
13.Estero,[c] San Luis Obispo	1/31-12/36	Jan	50.2	NE	7.0	8.6	NW	8.0	(150)	(50.0)[f]
		Apr	18.7	NW	10.0	17.8	NE	5.0	(127)	(49.9)
		Jul	27.5	W	3.0	12.1	SW	4.0	(70)	(67.1)
		Oct	21.9	NE	7.0	19.2	W	4.0	(103)	(59.0)
14.Fairfield,[d] Solano (Travis AFB)	8/43-8/53	Jan	13.2	NNE	13.3	10.2	N	10.8	226	20.0
		Apr	38.3	SW	17.1	29.4	WSW	15.5	362	5.9
		Jul	52.6	SW	17.5	38.4	WSW	14.0	458	0.7
		Oct	26.7	SW	15.0	20.6	WSW	14.4	298	15.0
15.Fort Bragg,[d] Mendocino	1/43-5/45	Jan	20.4	ESE	9.5	12.4	E	9.8	194	15.8
		Apr	31.1	NW	12.3	14.1	NNW	10.7	226	13.6
		Jul	15.3	NW	7.0	12.9	SW	6.0	149	25.1
		Oct	12.6	NNW	8.0	15.8	SE	8.4	156	22.5
16.Fresno,[d] Fresno	5/50-4/55	Jan	14.0	SE	7.2	11.0	NW	7.5	139	32.0
		Apr	29.0	NW	8.6	15.0	WNW	8.4	163	23.0
		Jul	27.0	WNW	8.8	25.0	NW	6.9	158	21.0
		Oct	19.0	NW	6.7	13.0	WNW	7.2	125	37.0

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary Frequency (%)	Primary Direction	Primary Mean[a] Speed (mph)	Secondary Frequency (%)	Secondary Direction	Secondary Mean[b] Speed (mph)	Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
17. Hollister,[c] San Benito	7/43-2/45	Jan	34.4	W	5.1	17.2	E	3.6	116	65.0
		Apr	32.2	SW	13.6	26.7	W	3.5	237	44.1
		Jul	40.3	W	11.7	24.2	SW	3.7	260	26.9
		Oct	35.0	W	7.7	14.5	E	3.3	152	52.1
18. Inyokern,[c] Kern Naval Ord. Test Station	4/45-12/52	Jan	16.1	SW	12.1	8.4	W	12.8	143	33.1
		Apr	19.5	SW	15.3	11.0	W	14.5	281	16.8
		Jul	24.5	SW	14.0	15.7	S	13.5	149	16.5
		Oct	20.7	SW	12.4	9.3	S	11.7	118	21.1
19. Lemoore,[d] Kings 36°15'N 119°57'W	1/42-7/44	Jan	12.0	SE	7.9	8.8	NNW	9.9	149	33.2
		Apr	22.9	NNW	10.8	14.3	NW	8.8	197	13.4
		Jul	31.2	NNW	10.3	17.7	NW	8.5	202	9.1
		Oct	18.3	N	9.0	14.8	NNW	9.4	175	15.6
20. Livermore,[d] Alameda	1/34-12/38	Jan	14.5	ENE	-	14.1	NE	-[e]	-[e]	23.2
		Apr	16.6	W	-	16.4	WSW	-	-	19.2
		Jul	27.4	WNW	-	22.6	W	-	-	14.2
		Oct	10.4	W	-	9.5	WNW	-	-	30.2
21. Long Beach,[d] Los Angeles	1/43-8/53 less 2/44, 7/45, 2/47	Jan	13.5	NW	5.6	7.2	W	8.3	108	47.6
		Apr	11.6	W	10.7	9.2	NW	7.5	139	36.7
		Jul	14.5	NW	8.1	11.7	S	7.4	139	32.6
		Oct	12.3	NW	6.8	8.7	WNW	6.7	106	48.0
22. Los Alamitos,[c] Orange	4/45-12/52	Jan	11.6	NE	7.5	8.1	SW	8.8	173	19.1
		Apr	16.9	SW	11.4	7.9	SSW	10.6	173	23.3
		Jul	19.7	SW	10.7	11.4	SSW	10.1	145	32.2
		Oct	15.5	SW	10.7	5.8	NW	6.8	138	31.5
23. Los Angeles,[d] Los Angeles (Airport)	5/50-4/55	Jan	11.0	W	6.5	10.0	ENE	5.6	142	31.0
		Apr	22.0	WSW	10.7	20.0	W	9.7	178	25.0
		Jul	29.0	WSW	8.9	20.0	W	8.1	144	34.0
		Oct	20.0	WSW	8.0	17.0	W	7.8	115	44.0
24. Marysville,[d] Yuba (Beale AFB)	8/43-10/44	Jan	18.0	NW	10.2	10.9	SE	7.3	163	29.0
		Apr	35.7	SE	8.7	11.7	SSE	11.1	199	14.6
		Jul	32.1	SE	9.9	20.0	S	7.9	192	15.2
		Oct	19.9	SE	8.2	9.6	NW	8.4	134	35.3

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary			Secondary			Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
			Frequency (%)	Direction	Mean[a] Speed (mph)	Frequency (%)	Direction	Mean[b] Speed (mph)		
25.Mather AFB,[d] Sacramento	9/41-12/51	Jan	12.6	S	11.4	11.0	SSE	15.0	168	38.0
		Apr	14.0	S	9.5	11.1	SSE	10.2	181	23.0
		Jul	24.7	S	9.6	23.3	SSW	10.8	226	6.0
		Oct	12.2	S	8.7	8.6	SSE	9.2	146	34.0
26.McClelland AFB,[d] Sacramento	6/40-6/50	Jan	15.3	SE	9.0	15.2	SSE		209	20.0
		Apr	20.8	S	10.3	18.3	SE		207	12.0
		Jul	35.8	S	11.1	22.4	SSE		230	6.0
		Oct	18.3	SE	7.1	14.8	S		175	22.0
27.Merced,[d] Merced (Castle AFB)	4/42-12/52	Jan	15.3	SE	9.2	10.3	NW	8.8	149	40.5
		Apr	24.2	NNW	11.7	20.2	N	10.0	214	17.3
		Jul	39.4	NW	8.9	26.3	NNW	10.2	211	9.5
		Oct	23.2	NW	8.9	16.4	NNW	9.6	158	28.3
28.Mintor AFB,[d] Kern	10/41-1/46	Jan	14.0	SE	5.9	10.5	NW	5.8	110	42.0
		Apr	16.7	N	8.2	14.8	NW	9.2	170	14.0
		Jul	26.2	N	7.3	19.2	NW	8.6	166	18.0
		Oct	14.8	N	5.4	11.4	NW	6.8	115	28.0
29.Miramar NAS,[d] San Diego	7/47-12/53	Jan	19.7	E	7.4	8.4	NW	6.6	136	16.0[g]
		Apr	12.4	WNW	7.8	11.0	W	7.6	138	20.0[g]
		Jul	15.0	WNW	6.7	13.8	NW	6.3	121	23.0[g]
		Oct	13.8	NW	6.5	11.0	WNW	7.3	124	23.6[g]
30.Moffet Field NAS,[d] Santa Clara	3/45-12/52	Jan	11.8	SE	10.8	9.0	SSE	10.7	139	37.4
		Apr	16.0	NNW	11.8	14.4	NW	11.0	174	25.5
		Jul	28.6	NNW	13.8	10.2	NW	11.0	184	24.4
		Oct	13.5	NNW	9.1	10.9	NW	9.5	130	39.0
31.Montague,[d] Siskiyou	1/34-12/38	Jan	8.8	S	-[e]	5.6	E	-[e]	-[e]	59.0
		Apr	12.5	NW	-	9.3	S	-	-	37.0
		Jul	15.8	N	-	11.1	NW	-	-	35.0
		Oct	9.9	S	-	8.3	NE	-	-	52.0
32.Muroc,[d] Kern (Edwards AFB)	1/42-4/55	Jan	11.0	WSW	13.1	10.7	SW	9.9	168	45.1
		Apr	22.6	SW	13.8	19.9	WSW	15.7	286	17.2
		Jul	33.9	SW	12.9	22.8	WSW	15.1	286	10.8
		Oct	17.1	SW	10.1	13.8	WSW	12.3	182	34.7

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary			Secondary			Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
			Frequency (%)	Direction	Mean[a] Speed (mph)	Frequency (%)	Direction	Mean[b] Speed (mph)		
33. Needles[d] San Bernardino	9/40-8/41	Jan	14.7	NW	-[e]	7.9	E	-[e]	(187)[e]	31.0
		Apr	9.0	SSW	-	8.7	NNW	-	(204)	20.0
		Jul	10.4	SW	-	10.1	NNW	-	(217)	21.0
		Oct	12.4	SW	-	9.4	S	-	(193)	30.0
34. Oakland,[d] Alameda	5/50-4/55	Jan	13.0	SE	7.8	11.0	SSE	10.4	127	45.0
		Apr	23.0	W	10.4	16.0	WSW	9.9	190	26.0
		Jul	28.0	WNW	9.6	20.0	W	9.6	180	22.0
		Oct	13.0	W	8.6	12.0	WNW	7.8	125	46.0
35. Oceanside,[d] San Diego	1/34-12/38	Jan	30.8	NE	-[e]	12.8	NW	-[e]	(259)[e]	8.0
		Apr	16.7	W	-	15.2	NW	-	(231)[e]	10.0
		Jul	23.9	W	-	11.9	SW	-	(193)[e]	22.0
		Oct	21.8	NE	-	14.7	W	-	(214)[e]	15.0
36. Palmdale,[d] Los Angeles	1/34-12/41 plus 11/48-10/52	Jan	22.4	SW	10.9	11.4	NW	7.8	209	21.5
		Apr	33.3	SW	13.6	9.5	WSW	13.3	276	10.5
		Jul	46.6	SW	13.9	10.3	WSW	14.6	271	10.2
		Oct	27.3	SW	11.0	8.8	S	6.1	206	18.3
37. Paso Robles,[c] San Luis Obispo	12/41-5/42	Jan	10.7	SW	7.4	7.3	N	5.5	(101)[e]	(55.0)[f]
		Apr	14.6	WSW	9.6	11.6	NNW	9.6	(192)[e]	(28.9)[f]
		Jul	-	(SW)[h]	-	-	(NW)[h]	-	-	(35.0)[f]
		Oct	-	(NNW)[h]	-	-	(SW)[h]	-	-	(40.0)[f]
38. Pittsburgh,[d] Contra Costa Dow Chem. Company	10/54-9/57	Jan	14.1	E	3.0	12.5	ESE	9.5	162	33.7
		Apr	21.0	WNW	13.6	19.0	W	12.8	265	5.0
		Jul	36.0	WNW	14.8	33.0	NW	15.0	295	8.6
		Oct	22.7	WSW	9.8	20.8	W	12.7	216	20.4
39. Point Arena,[c] Mendocino	1/37-12/42	Jan	34.7	SE	-[e]	9.5	NNE	-[e]	-[e]	(8.4)[f]
		Apr	33.0	NNW	-	26.0	N	-	-	(5.4)[f]
		Jul	36.0	N	-	18.0	NW	-	-	(8.2)[f]
		Oct	39.0	N	-	17.0	SE	-	-	(7.2)[f]
40. Point Arguello,[c] Santa Barbara	5/35-11/42	Jan	22.5	N	13.8	15.1	SE	15.6	(269)[e]	(16.7)[f]
		Apr	47.8	N	16.8	9.3	NW	16.6	(355)[e]	(7.3)[f]
		Jul	48.6	N	16.9	10.0	NNW	21.1	(360)[e]	(8.3)[f]
		Oct	44.2	N	14.7	8.6	NW	15.3	(295)[e]	(14.1)[f]

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary Frequency (%)	Primary Direction	Primary Mean[a] Speed (mph)	Secondary Frequency (%)	Secondary Direction	Secondary Mean[b] Speed (mph)	Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
41. Point Mugu,[c] Ventura 34°7'W 119°7'W	2/46-12/53	Jan	18.5	NE	8.1	18.1	N	7.5	233	17.1
		Apr	20.1	W	13.1	8.4	SW	8.9	185	23.7
		Jul	21.2	W	10.5	9.2	WSW	10.0	155	26.8
		Oct	14.7	W	11.3	10.7	N	6.2	160	24.6
42. Point Reyes,[c] Marin	3/38-12/41 less 9/11/38	Jan	19.0	E	10.0	18.0	SE	14.0	-[e]	-[f]
		Apr	35.0	NW	20.0	25.0	N	17.0	-	-
		Jul	44.0	NW	11.0	9.0	W	9.0	-	-
		Oct	35.0	NW	11.0	8.0	NNW	11.0	-	-
43. Portrero Hill,[d] Solano 38°18'N 121°50'W	1/35-12/38	Jan	15.2	NNE	-[e]	11.1	N	-[e]	-[f]	18.1
		Apr	24.8	WSW	-	17.2	SW	-	-	5.8
		Jul	44.0	SW	-	30.0	WSW	-	-	0.8
		Oct	24.0	WSW	-	16.0	W	-	-	4.7
44. Red Bluff,[d] Tehema	9/52-8/57	Jan	17.2	NW	7.0	17.1	SSE	17.9	242	15.3
		Apr	19.2	SSE	12.8	15.1	NNW	10.8	235	11.6
		Jul	22.7	SSE	10.7	9.0	NNW	8.8	198	14.8
		Oct	20.7	NW	10.0	17.6	NNW	8.6	194	16.4
45. Redding[d] Shasta	1/29-12/38	Jan	35.0	NW	-[e]	11.0	N	-[e]	(213)[e]	18.0
		Apr	25.0	NW	-	11.0	S	-	(224)[d]	11.8
		Jul	30.0	NW	-	16.0	SE	-	(218)[d]	9.1
		Oct	38.0	NW	-	15.0	N	-	(219)[d]	11.0
46. Riverside,[d] Riverside	2/36-5/53	Jan	9.9	NNE	7.2	7.9	NW	7.4	125	24.8
		Apr	18.7	NW	9.2	11.3	W	10.3	151	20.2
		Jul	31.3	NW	10.0	14.7	WNW	11.1	163	23.6
		Oct	16.4	NW	8.8	9.4	WNW	9.4	115	29.7
47. Sacramento,[d] Sacramento (Airport)	3/50-2/55	Jan	18.0	SE	12.2	16.0	SSE	15.9	242	18.0
		Apr	23.0	SW	12.3	10.0	SE	8.5	235	12.0
		Jul	29.0	SW	12.2	18.0	SSW	13.0	250	7.0
		Oct	14.0	SW	9.7	11.0	NNW	11.0	187	24.0
48. Salinas,[d] Monterey	11/41-6/44	Jan	36.4	SE	13.4	10.3	ESE	11.5	218	26.7
		Apr	18.6	W	11.3	16.2	WNW	11.0	209	21.2
		Jul	32.3	NW	10.1	24.0	WNW	11.4	218	12.1
		Oct	21.5	NW	9.0	15.6	SE	8.4	180	18.5

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary			Secondary			Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
			Frequency (%)	Direction	Mean[a] Speed (mph)	Frequency (%)	Direction	Mean[b] Speed (mph)		
49. San Bernardino,[d] San Bernardino (Norton AFB)	1/46-2/55	Jan	12.4	E	6.0	8.6	SE	6.3	122	44.4
		Apr	17.0	SW	7.1	10.4	W	7.9	115	43.2
		Jul	20.2	SW	7.9	15.5	WSW	8.8	115	45.7
		Oct	10.3	SW	7.0	8.4	WSW	7.8	91	54.6
50. San Diego,[d] San Diego (Lindbergh Field)	9/49-8/54	Jan	10.0	NNE	3.7	8.0	WNW	8.6	132	39.0
		Apr	12.1	W	8.9	12.0	SW	8.5	166	19.0
		Jul	14.0	WNW	7.9	13.0	SSW	7.3	156	15.0
		Oct	15.0	N	3.7	11.0	WNW	8.3	137	32.0
51. San Francisco,[d] San Mateo (Airport)	5/50-4/55	Jan	10.0	SE	8.1	9.0	WNW	11.4	194	27.0
		Apr	29.0	WNW	16.2	19.0	W	14.4	302	9.0
		Jul	28.0	WNW	14.9	24.0	NW	15.5	343	14.0
		Oct	25.0	WNW	12.9	18.0	W	12.3	242	39.0
52. San Jose,[d] Santa Clara (Dept. of Public Works)	7/37-6/47	Jan	22.3	SE	-[e]	21.8	NW	-[e]	-[e]	26.2
		Apr	43.5	NW	-	11.2	SE	-	-	23.0
		Jul	51.1	NW	-	13.1	SE	-	-	19.6
		Oct	34.6	NW	-	12.6	SE	-	-	25.5
53. San Pablo,[c] Contra Costa	6/29-3/30 1/31-2/39	Jan	23.5	NE	8.7	16.8	NNE	7.6	(110)[e]	(66.2)[f]
		Apr	32.7	SSW	11.1	26.9	SW	9.7	(161)[e]	(51.6)[f]
		Jul	55.0	SSW	14.3	30.7	SW	16.1	(348)[e]	(17.3)[f]
		Oct	39.1	SSW	7.7	26.4	SW	6.2	(127)[e]	(61.0)[f]
54. San Rafael,[d] Marin (Hamilton AFB)	3/39-6/55	Jan	7.9	ESE	8.9	7.1	NW	7.9	132	45.8
		Apr	16.0	NW	9.4	6.4	SE	7.9	149	37.0
		Jul	14.1	SE	10.3	11.8	NW	8.9	151	35.3
		Oct	11.8	NW	7.1	10.1	SE	7.1	110	51.5
55. Santa Barbara,[d] Santa Barbara (Airport)	1/48-12/55	Jan	20.2	NE	3.2	19.2	WSW	6.1	76	45.4
		Apr	34.4	WSW	8.1	16.9	SE	6.3	115	27.8
		Jul	52.2	SW	5.5	33.9	E	5.1	109	44.8
		Oct	36.2	WSW	7.2	17.2	NE	3.1	72	65.6

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary			Secondary			Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
			Frequency (%)	Direction	Mean[a] Speed (mph)	Frequency (%)	Direction	Mean[b] Speed (mph)		
56.Santa Maria[d] Santa Barbara	1/43-12/55	Jan	14.0	ESE	9.8	13.4	W	10.7	190	20.6
		Apr	28.6	W	12.1	10.7	SE	9.8	203	28.1
		Jul	37.5	W	11.1	9.6	NW	9.6	166	35.6
		Oct	22.5	W	10.9	10.8	SE	8.2	178	31.3
57.Santa Rosa,[d] Sonoma (AAB)	4/43-12/45	Jan	11.8	NW	7.6	10.4	SE	3.9	101	46.6
		Apr	14.5	SE	6.0	13.6	NW	11.5	173	31.8
		Jul	24.0	SSE	8.9	18.6	S	8.5	163	29.5
		Oct	12.2	SSE	7.4	9.3	S	12.7	108	51.6
58.Saugus,[d] Los Angeles	1/54-12/38	Jan	13.5	NW	-[e]	12.7	SE	-[e]	-[e]	31.0
		Apr	10.0	SSE	-	9.8	SE	-	-	36.0
		Jul	27.0	SE	-	11.0	S	-	-	39.0
		Oct	16.0	SE	-	15.0	S	-	-	37.0
59.Silver Lake,[d] San Bernadino	5/40-7/41	Jan	11.0	NW	-[e]	10.0	SE	-[e]	-[e]	41.0
		Apr	17.0	SE	-	12.0	S	-	-	17.0
		Jul	23.0	SE	-	18.0	S	-	-	11.0
		Oct	18.0	SE	-	10.0	S	-	-	35.0
60.Stockton,[d] Stanislaus	1/41-12/45	Jan	17.9	SE	8.7	9.0	W	5.1	134	40.0
		Apr	19.4	WNW	8.1	15.5	W	7.8	180	24.3
		Jul	28.4	WNW	7.4	19.9	NW	5.6	161	22.1
		Oct	19.7	WNW	7.0	14.0	NW	7.0	137	31.1
61.Taft,[d] Kern (Gardiner Airport)	12/41-2/45	Jan	16.0	SW	4.3	11.9	SSW	3.5	89	55.0
		Apr	18.0	N	7.4	14.7	SW	6.3	139	29.6
		Jul	18.4?	WSW	8.5	15.4	NNE	7.2	156	18.9
		Oct	22.7	SW	5.3	16.1	WSW	5.6	130	30.1
62.Tehatchapi,[d] Kern	11/42-12/44	Jan	31.3	SE	9.9	15.1	NW	10.5	216	14.5
		Apr	35.6	NW	10.5	20.1	WNW	11.4	226	13.0
		Jul	38.0	NW	10.3	17.2	W	6.4	190	15.2
		Oct	20.2	NW	9.9	14.3	SE	6.1	168	27.2
63.Thermal,[d] Riverside	7/43-2/45	Jan	19.8	NNW	6.7	14.0	NW	6.4	144	14.4
		Apr	37.0	NNW	12.6	14.7	NW	10.1	245	4.3
		Jul	28.5	NW	10.1	10.6	NNW	11.8	199	17.3
		Oct	24.3	N	7.1	19.4	NNW	8.6	173	12.9

Table B-I (Cont'd.)

Station, County	Period of Record	Month	Primary Frequency (%)	Primary Direction	Primary Mean[a] Speed (mph)	Secondary Frequency (%)	Secondary Direction	Secondary Mean[b] Speed (mph)	Mean 24-hr Wind Movement (mi)	% Time Wind Is Less Than 4 mph
64. Victorville,[d] San Bernadino	2/42-9/54	Jan	11.3	SE	7.2	10.9	SSE	11.3	206	20.2
		Apr	13.2	W	17.8	11.9	S	13.1	281	9.3
		Jul	15.7	SSE	10.4	12.3	SE	8.2	221	11.9
		Oct	14.0	SE	8.1	11.9	SSE	10.3	218	9.4
65. Williams,[d] Colusa	1/34-12/38	Jan	17.0	NW	-[e]	17.0	SE	-[e]	(244)[e]	21.0
		Apr	17.0	SE	-	12.0	NW	-	(234)[e]	16.0
		Jul	22.0	SE	-	11.0	E	-	(216)[e]	18.0
		Oct	16.0	W	-	13.0	SE	-	(224)[e]	17.0

Notes:

a - Mean speed for indicated direction only
b - Calculated from mean wind speed for month
c - Based on 4-hourly observations or hourly observations for less than 24 hrs
d - Complete 24-hr, hourly observations
e - Coarse speed groups in original tabulations preclude accurate calculation
f - Representativeness questionable because of observation schedule
g - Less than 3 mph
h - Estimated

Data Sources:

Climatography of U.S. No. 30-4, Summary of Hourly Observations
Local Climatological Data, Supplement published and unpublished (WB Form 5108)
Unpublished Air Force Air Weather Service, Summary of Surface Observations, Part A
Unpublished Navy Aerological Service Weather Summaries SMAR (REV)
WB Form 1139D Surface Wind Summary

Table B-II

WIND MOVEMENT DATA FOR EVAPORATION STATIONS[a]

Station	County	Years of Record	Month	Corrected[b] 24-hr Wind Movement	Wind Factor
Burlingame	San Mateo	2-1/2	Jan	136	2.7
			Apr	241	
			Jul	281	
			Oct	185	
Chico Expt. Station	Butte	6-1/2	Jan	176	3.0
			Apr	128	
			Jul	108	
			Oct	86	
Chula Vista	San Diego	30	Jan	124	1.7
			Apr	184	
			Jul	171	
			Oct	132	
Davis Expt. Station	Yolo	8	Jan	183	3.0
			Apr	172	
			Jul	149	
			Oct	136	
Independence	Inyo	6	Jan	154	1.7
			Apr	211	
			Jul	170	
			Oct	151	
Kettleman City	King	2-1/2	Jan	163	2.7
			Apr	219	
			Jul	191	
			Oct	157	
Lodi	San Joaquin	8	Jan	184	3.0
			Apr	188	
			Jul	163	
			Oct	108	
Mandeville Island	San Joaquin	2-1/2	Jan	191	1.7
			Apr	282	
			Jul	324	
			Oct	208	
Newark	Alameda	8	Jan	134	2.7
			Apr		
			Jul		
			Oct	138	
Tracy Pump Station	Alameda	2-3/4	Jan	118	1.7
			Apr	240	
			Jul	378	
			Oct	178	

Table B-II (Cont'd.)

Station	County	Years of Record	Month	Corrected[b] 24-hr Wind Movement	Wind Factor
Walnut Grove	Sacramento	2-1/2	Jan	162	3.0
			Apr	198	
			Jul	212	
			Oct	111	

a - Sources, Climatological Data, Calif. and Bulletin W Sections 16, 17, and 18

b - Evaporation pan anemometers are located 1-1/2 to 2 ft above ground level. To make the monthly accumulation of miles of wind reported compatible with the standard anemometer height the following computation has been performed:

$$\frac{\text{Monthly Total Miles}}{31} \times \text{Wind Factor} = \text{24-hr Wind Movement}$$

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